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ABSTRACT

The International Union of Pure and Applied Chemistry (IUPAC) of Unesco promotes cooperation and the furtherance of chemistry worldwide. The workshop was structured so that contributions representing a wide range of interests in chemistry and chemical education could be presented. The papers include: (1) descriptions of some simple equipment that can be made from easily accessible materials (such as low cost polarimeters, cation-exchangers, magnetic balances, pH meters, and photometers); (2) accounts of instructional programs at various universities which use locally produced equipment (including universities in Thailand, Nigeria, Czechoslovakia, Brazil, Sri Lanka, India, and West Germany); and (3) articles that outlined trends and issues in international chemical education. The agenda for the workshop and a list of participants are included. (TW)

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ED 277 590

PROCEEDINGS OF THE WORKSHOP ON LOCALLY PRODUCED LABORATORY EQUIPMENT FOR CHEMICAL EDUCATION

COPENHAGEN 11-17 AUGUST 1983

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PROCEEDINGS of
the WORKSHOP on

LOCALLY PRODUCED LABORATORY EQUIPMENT FOR CHEMICAL EDUCATION

COPENHAGEN. 11 - 17 AUGUST 1983

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P R E F A C E

The International Union of Pure and Applied Chemistry promotes cooperation and the furtherance of chemistry worldwide. It has over 40 commissions and sections which are the internationally recognized authorities, dealing with the regulation and standardization of a myriad of activities, from nomenclature of compounds to commissions which advise on food contaminents, atmospheric environment and water quality.

In 1964, IUPAC formed the Committee on Teaching of Chemistry, and the chairmen who have so far held office are R.S. Nyholm (Australia), R.W. Parry (USA) and C.N.R. Rao (India). Under Professor Rao's leadership, CTC became co-partners in a series of Unesco-IUPAC workshops in developing countries, aimed at encouraging laboratory work in colleges and universities. (We are also acutely aware of the need to do the same at school level as will be apparent from these Proceedings). However, there are severe economic constraints which discourage practical work at all levels.

We initiated a pilot project in October 1979 at the University of Delhi to develop locally-produced equipment, and the papers by Dr. Sane, Dr. Srivastava and Dr. Seth describe some of this work. The philosophy underlying this work is as important as the materials developed and produced.

Using this project as a launching-pad, we have been organizing workshops in several regions. Mention is made, for example, by Mr. Steward and other participants in this Workshop. Professor Haider - in Bangladesh - and Professors Ramakrishna and Selvaratnam - in Sri Lanka - are helping to organize workshops in 1984 and 1985. Workshops in São Paulo - described by Dr. Srivastava - and in various centres in India have also been held this year.

This is all very encouraging but we need help in many ways. We need new ideas; we need people who can help

develop these ideas into action; we need people to help us spread the work into their own institutions and their own countries; we, of course, need financial assistance; above all, we need the encouragement that comes from having distinguished practitioners from other fields take notice and approve of the work.

It was with great pleasure that IUPAC CTC found a new ally in Erik Thulstrup who agreed not only to act as co-chairman of this, our first European workshop in locally-produced equipment, but also to lend his broad shoulders to all the detailed work such an event, on an international scale, demands.

The Workshop attracted a wide range of contributions, as can be readily seen from the papers. It was deliberately so; we tried our best to ensure that there was a mix of teachers from all levels and also to ensure that we had leading chemists in developing countries who could give us their wisdom, experience and expertise.

A final decision on whether a workshop is successful or not depends on whether anything is accomplished in the future. One can only look back after a few years to judge. But I am optimistic about this one - if only to have been a member of a group of scientists - chemists and physicists - who met the challenge, worked so hard and with good humour, helped us formulate some of our future plans. I am extremely grateful not only to Professor Thulstrup but to all his colleagues at the Royal Danish School of Educational Studies and to Unesco, Paris, and the Danish National Commission for Unesco who made it all possible.

D.J. Waddington

Chairman of the IUPAC Committee
on Teaching of Chemistry

C O N T R I B U T E D

P A P E R S

A LOW-COST POLARIMETER

Gunnar Cederberg, Department of Chemistry,
Royal Danish School of Educational Studies,
Emdrupvej 115 B, 2400 Copenhagen NV.

As it is known, some compounds - especially some organics - are optical active because they affect the polarized light. Optical activity is the ability to rotate the plane of polarized light. By means of a polarimeter it is possible quantitatively to measure the effect of substances on polarized light.

A schematic diagram of a polarimeter shows the functioning parts (Figure 1):

1) a source of light which yields monochromatic light
2) a polarizer
3) a sample tube
4) an analyzer, and
5) a detector (the eye)

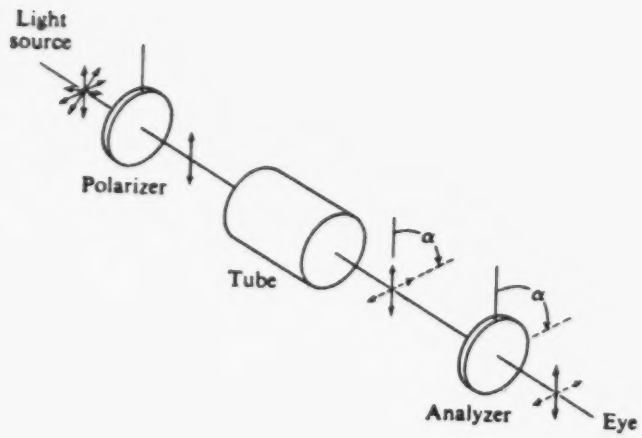


Figure 1. Schematic representation of a polarimeter. Solid lines: before rotation. Broken lines: after rotation. α is angle of rotation.

Commercial equipment for precision measurement of rotation for optical active compounds is expensive. A low-cost polarimeter providing an accuracy of $\pm$ 1° can be constructed as shown in Figure 2.

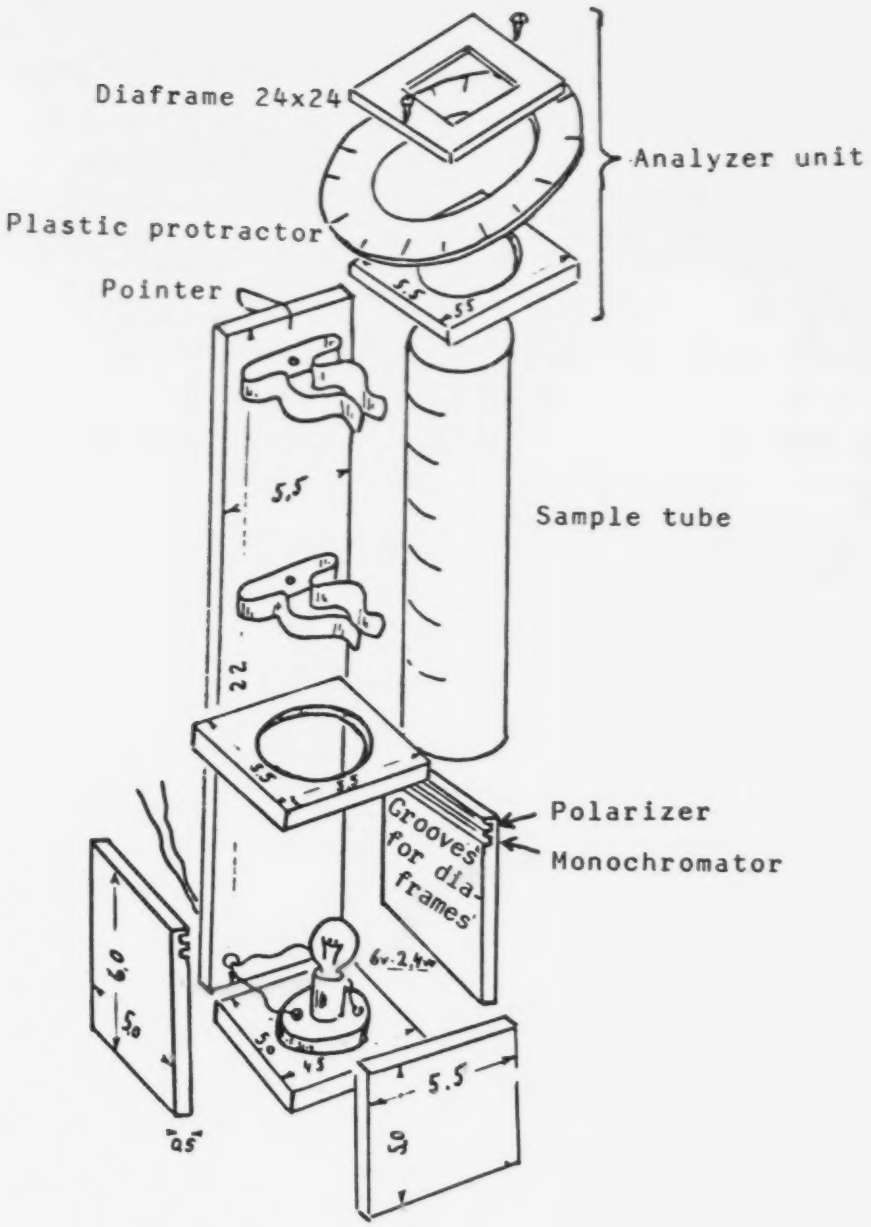


Figure 2.

Description:

The frame is made of plywood which can either be glued or nailed together.

As a light source is used a 6 volt flashlight bulb surrounded by reflecting material.

Colour filters are used as monochromator. With KODAK filter No. 73 light in the wavelength region 570 nm is obtained (close to the D-line of sodium); filters No. 74 and 75 provide light with wavelengths of 530 nm and 480 nm respectively.
It is convenient to place the filters in diaframes.

Both polarizer and analyzer are made of polaroid filters and are also placed in diaframes. The polarizer is placed just above the monochromator; both can easily be dismounted and replaced.

Between the polarizer and analyzer is placed the sample tube: a cylindrical preparation glass with a plane bottom. It can be fastened in the clips on the back wall of the polarimeter.

The analyzer is made of a round plywood disk. In the centre is drilled a hole with a diameter which corresponds exactly to the outside diameter of the sample tube. On the plywood disk is fastened a 360° protractor and a frame with polaroid filter analyzer. When the polarimeter is in use this analyzer unit is positioned on the sample tube so that its opening is placed in the hole of the plywood disk.

Directions for use.

1. Fill about 4/5 of the sample tube with a solvent and place it in the polarimeter.
2. Place the wanted colour filter and the polarizer in the polarimeter.
3. Turn on the light.
4. Place the analyzer unit horizontally on the sample tube.
5. Look from above at the filament. Then turn the analyzer to the position in which the filament is least visible.

6. Note the position of the pointer in relative to the protractor (0-position).

7. Weigh out an amount c g (e.g. 2o g) of the optically active substance, and dissolve it in water with a final volume of 1oo ml.

8. Repeat point 1-6 using the produced solution. Now the position of the pointer will be different from before. The difference between the two values indicates the optical rotation, α, in degrees. The number is given with a sign (+ or -): (+) in case the analyzer (seen from above) is turned to the right in 8. relative to the position observed in 6.

9. Measure the height, ℓ, of the solution in dm (decimeter).

10. The specific rotation $[\alpha]_\lambda$ at the given temperature and wavelenght λ is calculated according to the formula:

$$[\alpha]_\lambda = \frac{\alpha \cdot 100}{c \cdot \ell}$$

$[\alpha]_{570}$ nearly corresponds to $[\alpha]_D$.

The following simple experiments may be performed:

a) Determination of $[\alpha]_D$ for α-D-glucose (dissolved in water).

b) Mutarotation: $[\alpha]_D$ for α-D-glucose and β-D-glucose approach the same value after some time (several hours). If you add a few drops of NaOH-solution the speed will increase.

c) Determination of $[\alpha]_D$ for saccharose (aqueous solution).

d) Determination of the concentration of unknown saccharose solutions on the basis of the measured optical rotation.

e) Inversion of saccharose: $[\alpha]_D$ for saccharose is changed from about $+66^\circ$ to about $-4o^\circ$ by adding acid. The speed increases both as a result of higher temperature and lower pH.

f) When using different colour filters the specific rotation can be determined at several wawe lengths (optical rotatory dispersion, ORD).

g) Note that in case other substances and other solvents than water are used parts of the polarimeter may be damaged (e.g. dissolved).

A HOME-MADE pH-METER.

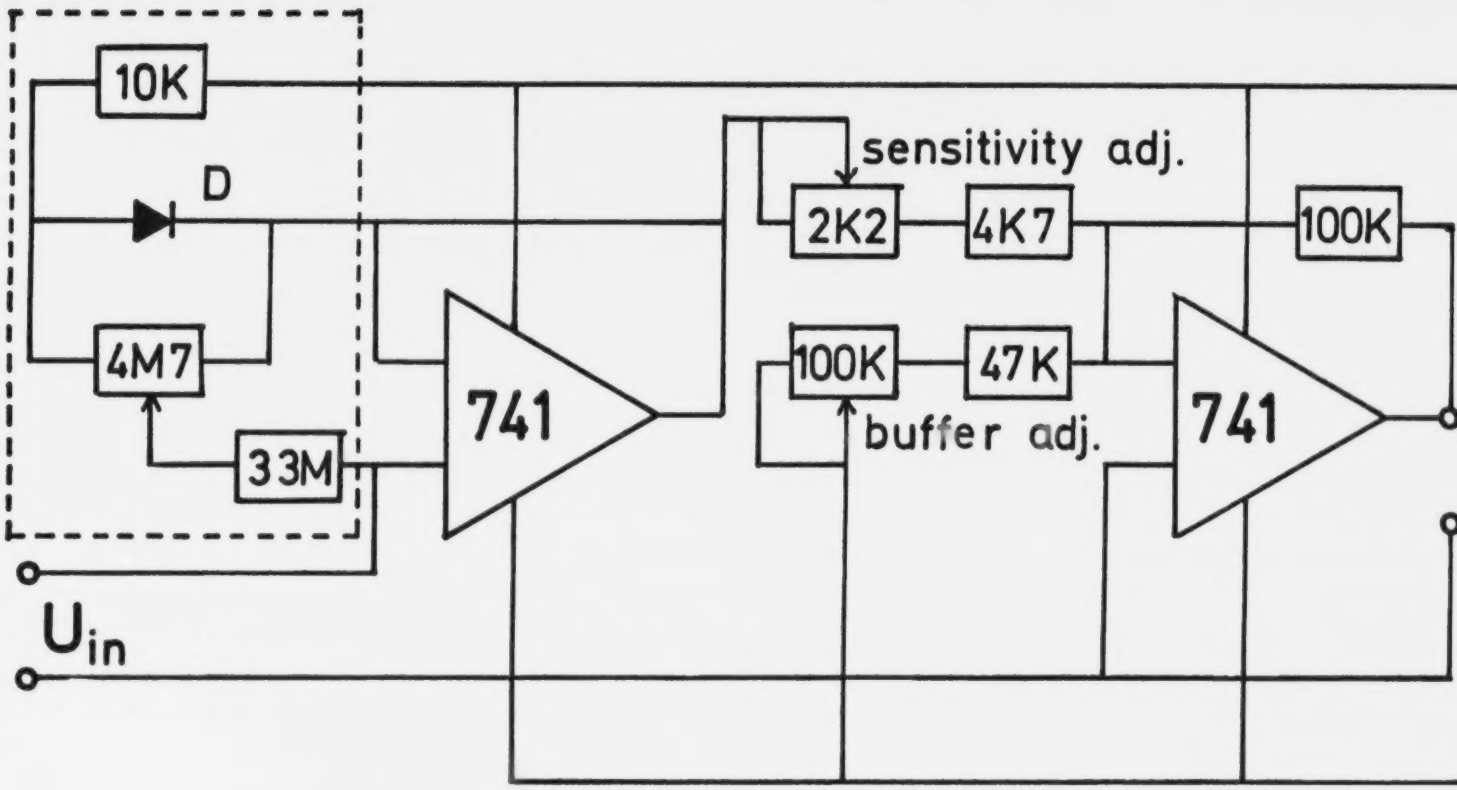
Jørn Johs. Christiansen, Royal Danish School of Educational Studies, Department of Chemistry, Emdrupvej 115 B, DK-2400 Copenhagen NV, Denmark.

The measurements of pH of the solutions are important in chemistry as well as in biochemistry and biological teaching. pH measurements are also of great economical importance e.g. for agricultural practice. Fortunately it is possible to construct a pH-meter for teaching purpose, using the rugged electrodes and with an easily constructed electronic part. Even the pupil can use it because of the lack of delicacy. Destruction apart from pure wanton destruction is not probable.

The parts of the pH-meter are two electrodes, a salt bridge, a buffer solution and an electronic part with a voltmeter. An electrode is a bit of antimony on which a lead is soldered. The solder and wire is covered with epoxy resin up to the insulation. You need two of these electrodes, one to place in the solution to investigate the other in a buffer solution with known pH-value. The two solutions are connected with a salt bridge. I prefer a plastic tubing, not too short, filled with a salt jelly as a salt bridge. This can be constructed as: a saturated solution of KCl is boiled with a few per cent agar agar for some minutes and then,suck up in the plastic tube while it is hot.

The electronic part uses two operational amplifiers, one as a voltage follower and the other as a summing amplifier. The figure shows the diagram I have used.

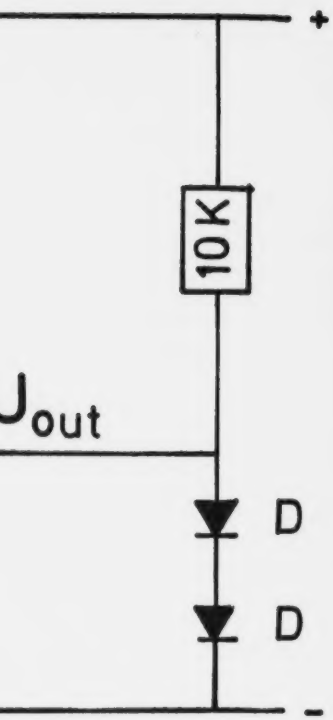
The circut enclosed in the dotted rectangle is compensating for the open circut current to the input of the voltage follower. The 4.7 MΩ potentiometer is adjusted so that the output voltage is the same whether the input terminals are connected to each other or not. The 2.2 kΩ potentiometer is for the sensitivity and the 100 kΩ potentiometer is the buffer control. The buffer control is adjusted with both electrodes in the same buffer solution. The sensitivity is adjusted using two buffer solutions with pH as different as practically possible, e.g. an



pH - Meter amplifier

58 mV is amplified to 1 V.

D: stabistor BZV46 - 2
2K2 pot. for sensitiv
100K pot. for buffer
4M7 pot. for offset c



V0
ty adj.
adj.
urrent adj.

acetic acid / acetate buffer and an ammonium ion / ammonia buffer.

The set up, ready to use, is then two electrodes, one in a buffer solution, a salt bridge, an electronic part and a voltmeter. One of the electrodes and one end of the salt bridge are placed in the solution to be investigated. This set up works well performing acid base titrations, measurements of pH-values of the buffer solutions, and in measuring pH in different degrees of dilution of strong and weak acids. I have tested this and I am convinced that with common acids and bases this pH-meter works well from pH 2 to pH 12. In my opinion it is adequate and cheap in use in elementary teaching.

In fact, the two electrodes are necessary for pH-measurements, and a pH-meter is nothing but a voltmeter with a special sensitivity and offset. This can be achieved easily with this set up. The flexibility of the salt bridge and the ruggedness of the sensing electrodes make fully up for the trouble using a reference buffer.

The principle behind this antimony electrode as a pH sensing electrode can be explained by the equilibrium between Sb, Sb_2O_3, H_2O and H^+

$$Sb_2O_3 + 6\ H^+ + 6\ e^- \rightleftarrows 2\ Sb + 3\ H_2O.$$

For the specialist (and purist) some details might not be well understood, but that is probably more so concerning the glass electrode. Solutions containing substances forming complexes with antimony as well as strongly reducing and oxidizing solution may cause trouble. But, are these solutions really necessary when the subject for the teaching are pH, acids and bases?

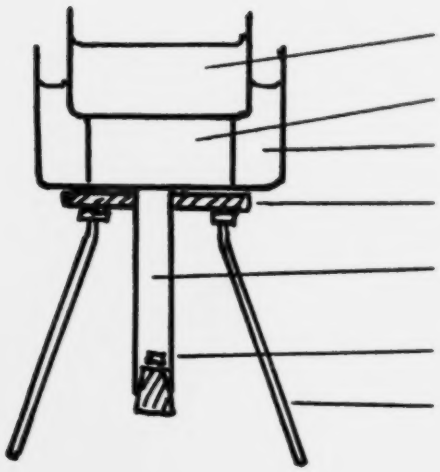
A HOME-MADE PHOTOMETER.

Jørn Johs. Christiansen, Royal Danish School of Educational Studies, Department of Chemistry, Emdrupvej 115 B, DK-2400 Copenhagen NV, Denmark.

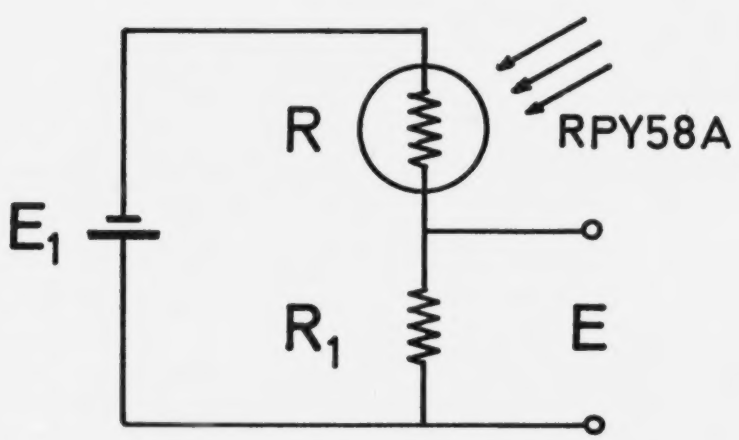
Carl Erik Berg, The State Teacher Training Institute at Emdrupborg, Emdrupvej 101, DK-2400 Copenhagen NV, Denmark.

The photometer we have constructed is unconventional in arrangement as the "optical" parts are placed vertical to each other. The use of variable sample thickness and of liquid filters are also unconventional. The figure shows the arrangement.

X — 60 W bulb 0.5 - 1 m above the sample cell



The sample cell is a crystallization dish or a beaker on a spacer in a larger crystallization dish containing the liquid filter. The light from a 60 W bulb is irradiated from the top, and at the bottom there is a detector, a photoresistor in a cardboard tube lined with mat black paper. The sample and the reagents can be poured into the sample cell as needed. The thickness of liquid in the cylindrical sample cell depends upon the quantity of the reagents and the sample. But the special feature of this photometer is that the substance is contained in an open cylindrical sample cell and that the attenuation of the light passing along the rotational axis of the cell therefore is independent of the degree of dilution. As a consequence the basic concept in making the useful analytical deductions is the amount of substance, not as ordinarily the concentration. The detector we have used is the photoresistor, RPY58A. We have $R = aL^{-\alpha}$ where R is resistance, L is illumination and a and α are constants. Using Ohm's law, the condition $R >> R_1$ and assuming R_1 and E_1 constant you will find $A = \log \frac{Io}{I} = \frac{1}{\alpha} \log \frac{Eo}{E}$.



An adjustment for 0 % and 100 % transmission is provided. As it is common practice to calibrate by means of standard solutions, the photoresistor is serving well in analytical determinations, e.g. testing Lambert's law, Beer's law and Lambert-Beer's law. But for determination of the molar absorption coefficients α must be known.

The detector is sensitive for infrared radiation, and the light bulb gives plenty of this. Therefore, an infrared filter is required, e.g. a $CuSO_4$ solution. 13 g $CuSO_4 \cdot 5H_2O$ per litre in a layer of 5 cm is a suitable filter, absorbing the infrared radiation and the outermost red light. Saturated $CuSO_4$ can also be used, and it has been found that dyes dissolved in $CuSO_4$ solution works well. The colour of the dye is chosen depending on the analysis to be made.

We believe that a photometer constructed after these principles will serve well in the elementary teaching when introducing photometry. Not least because of the direct use of amount of substance in evaluating the analytical results.

DETERMINATION OF GAS VOLUME IN URINE BAGS BY MEANS OF A MEASURING WEDGE OR PARALLEL PLATES AS FIXED MEASURES.

Jørn Johs. Christiansen, Royal Danish School of Educational Studies, Department of Chemistry, Emdrupvej 115 B, DK-2400 Copenhagen NV, Denmark.

The autumn 1968 was the first time when I used urine bags as gasometers in chemistry teaching experiments. To use a plastic bag as gasometer was not a new idea. Several producers of laboratory equipment were selling rather large and quite expensive bags for such uses. The new idea was the use of the mass produced and cheap urine bags as gasometers. The intension was to divide the experiment in a production phase and a phase where the gas was used or investigated. In most cases such stepwise division will make the experiment more easy to perform. The gas can quickly be transformed from the bag to an experimental set up and furthermore the use of a bag gives a clear impression of the amount of gas available for the experiment.

The bags can be used not only as gasometers, but also in cases where the reactions are performed by placing the gases together in the same bag. A solution of a gas in water can be made by pouring some water into a bag containing gas, and then shake it. You may also use the same technique when washing a gas with water or another adequate liquid. With a base in the bag it is possible to make air free of CO_2.

During the past 15 years the use of urine bags in chemistry experiments has become common practice in Danish primary schools and high schools. The most general type is a 1.5 litre bag without a non-return-valve and with a tube about 1 m long. Outside Denmark the application of urine bags in chemistry experiments is rarely known.

A urine bag can also be filled with a well defined known amount of gas. It is then possible to prepare a solution of known concentration of e.g. HCl, NH_3 or SO_2. These solutions can be used as standard solutions when titration analysis is introduced in the elementary chemistry teaching. The solutions of HCl and NH_3 can be used in acidimetry, the HCl-solution also in argentometry, and the SO_2-solution in redox titrations. It is quite simple to confine a well defined amount of gas in a bag. The urine bag is placed between two plates and filled with gas to the point at which it cannot be moved between the plates. Alternatively, the bag can be filled to a slight overpressure of 3o-1oo Pa (easily demonstrated as 3-1o mm H_2O). When the distance between the plates is 26 mm about 5oo ml is confined in a 1.5 litre bag. About 1 litre is confined when the distance is 4o mm. Plates of laminated plywood 22 cm x 28 cm are suitable. The accuracy, of course, depends on care and use of a reproducible technique in filling the bag. With care you may obtain a few per cent accuracy, and 5 per cent is easily obtained. It is thus possible to prepare the standard solutions directly on the basis of Avogadro's law. From a pedagogic point of view it is of interest to see whether this increases the understanding of the titration analysis. For students of chemical education it should be possible to handle the didactic as well as the practical problems in this investigation.

The gas content in an urine bag can be determined by placing the bag in a wedge-shaped space between two pieces of laminated plywood. Volumes from about 4oo to 12oo ml are measured conveniently with a 1.5 litre urine bag. A wedge increasing about 3.5 cm per m seems convenient. By means of the wedge it is possible to measure the amount of gas generated in an experiment; in addition you may follow the rate of reaction.

The experiments can be arranged both favouring quantitative and qualitative aspects, and you will find the proposed size of the bag easy to manipulate. I, therefore, think that most educators will find urine bags useful in the elementary chemistry teaching, in demonstration experiments as well as in pupil experiments.

If you do not like the name urine bag, I would suggest gas bag.

REDUCING THE COST OF TEACHING CHEMISTRY

P E Childs
Lecturer in Chemistry, Thomond College of Education, Limerick, Ireland

INTRODUCTION

The increasing cost of teaching chemistry is a matter of concern to chemistry teachers in developing and developed countries, at both second and third levels. Budgets are being cut, student numbers are increasing and due to inflation this year's money buys less than last year's. The result is that practical chemistry is becoming increasingly a luxury and a subject that is in essence experimental is being taught more at the blackboard than at the laboratory bench. Many chemistry teachers have been content to order what they needed from catalogues in times of economic boom, and faced with cut-backs they lack the initiative and skills of improvisation needed to adapt. Much of the early work in atomic structure, for example, was done using homemade equipment - the 'string and sealing wax' approach. Today's researchers, as well as teachers, cannot imagine science without complex, expensive grey boxes bought off-the-shelf. When times are hard and money is short we need to return to the roots of science and recover the spirit of improvisation and problem-solving that characterised early scientists and science teachers.

CHANGING THE ATTITUDES OF SCIENCE TEACHERS

Many of the problems lie in the initial training of science teachers. I have worked with science teachers in Uganda and Ireland and have found similar problems and similar attitudes. The training of teachers does not always encourage improvisation or problem-solving, or develop the necessary skills needed for making equipment themselves and the practice in doing so. There is a need too for in-service training where teachers are trained to make up their own apparatus and go away from the course with new skills and apparatus they have made themselves. Too little of the training of science teachers involves 'hands-on' experience which is vital for building confidence and skill, and too much is done by telling and showing. I have found that even demonstrating skills or actions is not adequate unless the

teachers get a chance to try it for themselves. And reading it in books or magazines is even less effective in transferring the skills and attitudes needed to make the resourceful science teacher. However, appropriate training can produce teachers who have the confidence and inclination to try things out, to improvise and adapt and apply ideas in print. Having produced the right sort of teacher through their initial or in-service training, it is then necessary to feed them with ideas and information on the making of equipment, the utilisation of waste materials, sources of material, etc. There are plenty of ideas and designs in the science teaching literacture which are largely unavailable to practising teachers. The dissemination of this information in a digestible form is an important step in reducing the cost of science teaching.

My own limited experience supports the validity of these ideas. I am involved in training science/chemistry teachers and we try to emphasise improvisation, problem-solving and resourcefulness early and often. The very first experience for incoming science students, fresh from school, is to make their own apparatus up for preparing gases - this involves cutting, flame-polishing and bending glass, putting glass through bungs, assembling and testing the apparatus. We encourage students to solve the problems they encounter themselves - failures are used as opportunities to learn and to reinforce correct ideas. More can be learnt from an experiment that goes wrong than from one that succeeds. On our in-service courses we stress 'hands-on' experience to increase confidence and develop skills, and basic practical skills, e.g. inserting glass tubing through rubber bungs, are most in demand. It is no good sending out plans or instructions for making apparatus unless the teachers at the receiving end have the confidence and some basic skills to try them out.

To reduce the cost of science teaching we need to -

(a) change the training of teachers to give them the necessary skills and confidence to improvise, adapt and innovate themselves;

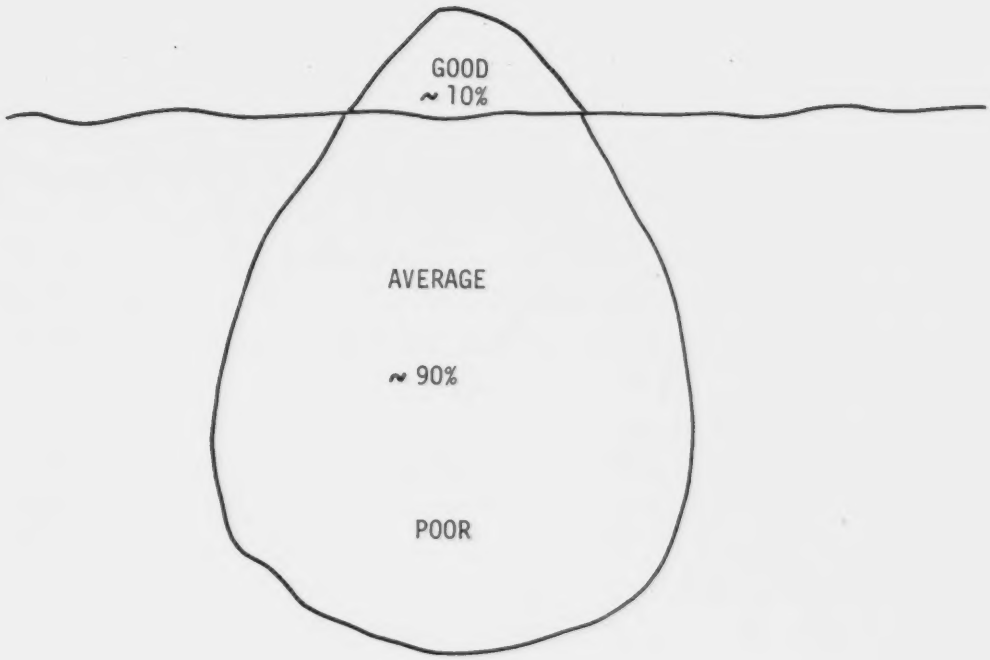
(b) in-service training is needed for older teachers to give them the same skills as in (a) plus refresher and advanced courses in making and designing equipment on a continuing basis;

(c) dissemination of ideas, tips, plans, instructions, etc., to teachers in the field which they can apply themselves using the skills and confidence developed through (c) and/or (b).

KEEP IT SIMPLE

From what I have said above it should be clear that my emphasis in this paper is on basic skills and simple apparatus. The situation with regard to the level of training and expertise of science teachers varies from one country to another. Every country has a small group of elite teachers who need little formal instruction - they are natural improvisers, good problem-solvers, keen course-attenders and avid readers of science-teaching publications. They represent the tip of the iceberg or the snout of the crocodile! My own feeling is that the vast majority of teachers in many countries need much more basic help to become better science teachers. I applaud the work of those producing low cost electronic equipment such as pH meters, conductivity meters, colorimeters etc., but I think we need to deal with more basic needs first - gas preparation apparatus, electrolysis cells, test-tube racks, etc., and more basic skills such as working with glass, wood, metal and plastic. If we look at second level chemistry/science courses and their equipment needs most of it is quite simple in design and can be fairly inexpensive. You can get a lot of test-tubes for the cost of even a home-made pH meter. The vast majority of experiments in these courses involve this simple equipment and relatively few experiments, even for advanced level courses, require sophisticated apparatus. If we are to reduce the cost of teaching chemistry/science we must attack the basic equipment first before moving on to more sophisticated items. The situation is probably different in physics to that in chemistry. There is also the additional cost of chemicals, which is a major consumable budget item, and another area where we need to take a hard look: what chemicals are used? how and why they are used ? is recovery and reuse possible ? A lot of money goes down the sinks of chemistry laboratories each year, more than is lost in breakages. Our use of chemicals and where they are obtained also needs serious study if the cost of chemistry teaching is to be significantly reduced and will also be considered below.

Figure 1 The 'iceberg' of science teaching



MATERIALS FOR CHEMISTRY TEACHING

I shall now attempt to classify the equipment, apparatus and chemicals used in chemistry courses at second level. This will often be similar to the requirements of introductory third-level courses in many countries, since many first year college or university courses emphasise basic chemistry for large numbers of students of varying ability or chemical background.

The materials used in chemistry teaching appear to be as follows -

1. chemicals

2. equipment and apparatus
   (a) glassware used for heating solids or solutions e.g. flasks, test-tubes, beakers, dishes;

   (b) glassware used as containers or measures but not used for heating e.g. volumetric flasks, drying bottles, desiccators, funnels, condensers, measuring cylinders;

   (c) miscellaneous items of metal or wood e.g. test-tube racks, stands and clamps, test-tube holders, heat sources (bunsen), thermometers;

   (d) simple instrumentation for measuring pH, conductivity, light absorption.

We need to identify which items can be made locally, redesigned or replaced by alternatives, in order to free money for buying items which cannot easily or conveniently be improvised or made locally. If there is sufficient demand and the resources are available it may be possible to make many items locally from local materials or from imported raw materials or components. As well as saving foreign exchange this approach will also produce jobs.

The following categories of materials can be identified in order of increasing cost:

(i) A. <u>Items which can be improvised or obtained directly from local sources or waste</u>
e.g. using glass or plastic jars as chemical containers or

reaction vessels; using available 'chemicals' such as common salt, sugar, petrol in experiments.
Here materials are already available and are substituted for laboratory apparatus or chemicals. Paradoxically this is easier in developed countries, where a much greater variety of materials are on sale and the quantity of useful waste is bigger, than in developing countries where the needs are greater. In Europe, for example, the amount of packaging materials thrown away is a major environmental problem - there is a surplus of unwanted glass, plastic and metal containers. In a developing country very little is thrown away and there is fierce competition for recycling old containers for a variety of purposes. Many possibilities for improvisation of apparatus and chemicals in rich countries would not be available to the science teacher in a poorer country.

B. Redesigning experiments to reduce cost

There is often more than one way to perform an experiment utilising different experimental set-ups and often that can result in simplification and lower-cost. A good example is the use of small-scale preparation: the glassware is cheaper, easier to handle, uses less chemicals and is much safer (Figure 2).

Figure 2 Small-Scale Versus Large-Scale Gas Preparation

(a) (b)

Typical relative costs:

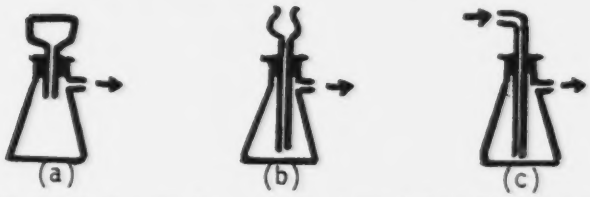
equipment	1	8
chemicals	1	4 - 10

We need to think about the purpose of experiments and the equipment used in order to devise alternative ways which are cheaper without sacrificing the point of the experiment. Can the equipment be redesigned to utilise local/waste material or to

permit local manufacture ? Can the experiment be done effectively in a less sophisticated way ? Can the same piece of equipment be used for different purposes ?

e.g. a filter flask is a very useful piece of equipment. It can be used as a filter flask (Figure 3(a)) a gas generator (3(b)), for drying a gas or bubbling it through a reagent (3(C)), etc., and even the filter flask can be replaced!

Figure 3 Uses of a Filter Flask



(ii) Simple items that can be manufactured locally from local materials

Many simple items of laboratory equipment can be made locally in a simple workshop, possibly inside the school. Instead of buying-in such equipment, often imported at great cost, it should be possible to make them on a local or national scale. Simple examples would be test-tube racks or laboratory stands. More complex items might be manufactured on a larger scale for sale within the country - this could include simple glassware or plastic substitutes. Some chemicals too can be made and distributed within the country on a fairly small scale, rather than importing packaged pure chemicals. There is opportunity here and in (iii) for local designs and innovations.

(iii) Partial or Complete assembly or packaging from imported parts or materials.

If it is not economic or feasible to make equipment or chemicals from local materials, cost savings can be made by assembly or repackaging of items bought in bulk. The cost of meters, for example, can be reduced by putting into boxes locally. Simple electronic equipment can be assembled locally from imported parts. Chemicals can be imported in bulk and repackaged in locally-made containers in convenient quantities for laboratory use.

(iv) Items of equipment or chemicals that must be imported in finished form.

This is the costliest option which generates little local employment and uses most foreign exchange. The aim should be to reduce this category of science teaching equipment to a minimum, thus freeing money to buy or make other items at lower cost using approaches (i), (ii) and (iii).

WORKSHOPS IN DESIGN AND IMPROVISATION

Workshops like this one or in-service courses for teachers can be used profitably as brainstorming sessions to generate new uses for old objects, or new solutions to existing problems. One way of doing this is to collect a box of waste objects and try and devise as many uses as possible for the objects in science classes. The box might contain, for example, plastic straws, wooden clothes pegs, pipecleaners, used gas-lighters, various empty containers of glass, metal or plastic. The idea is to stimulate teachers or trainee teachers to think of new ideas, to improvise and adapt and innovate - it is useful practice and may generate some new ideas into the bargain. Another approach is to think of an experiment or a piece of apparatus and think of alternative approaches or apparatus to fulfil the same function. An example might be an expensive glass or plastic laboratory desicator. The purpose is to keep things inside dry - so it must be airtight, chemically inert and capable of containing a drying agent. A variety of solutions can be envisaged - plastic tubs with sachets of drying agent, coffee jars with drying agent in the lids, biscuit tins painted and containing a drying agent inside a small, perforated tin.

DISSEMINATING IDEAS TO TEACHERS

A workshop like this is a luxury if it reinvents the wheel but doesn't generate new ideas and solutions. There are many good ideas already in use and often in print which would provide solutions for many of our problems. A good example would be a design for a solar water still published in J. Chem Educ.(48,49,1971), or various designs for cheap pipette fillers which avoid the need to buy expensive and often unreliable commercial pipette fillers (£3-£10+). The idea using a washing-up liquid bottle or similar squeezy container is the best I've seen (See Appendix 1).

But how do we get the information to the teachers who need it ? There needs to be an active programme to discover and evaluate ideas already in print, to generate collect and test new ideas. These tested and proven solutions, plans, designs or tips should then be published at low-cost in a simple do-it-yourself format, with step-by-step instructions, and made available to science teachers associations and science teaching centres who should be encouraged to use the information in courses or to send them out to teachers in schools. I am not thinking of once-off publications like the UNESCO Handbook but a more regular, perhaps loose-leaf, distribution of information sheets.This could be done internationally on a larger and more comprehensive scale and modified to meet national needs by its recipient. Needless to say I am envisaging a situation where such material would be copyright-free. The information sheets might consist of clear diagrammatic instructions followed by written instructions making translation easy. A sample is given in Appendix 1. National rapporteurs could send in ideas to UNESCO for collation and distribution.

LOCAL MANUFACTURE OF EQUIPMENT

If there is a substantial local market for laboratory equipment it is worth manufacturing selected items locally. These can either be straight copies of traditional items from local materials e.g. test-tube racks, metal stands, tripods, etc., or new designs using imported or local materials e.g. safety screens, electrolysis cells, etc. At least two Irish firms - Lennox Laboratory Supplies and Shaw Scientific - manufacture some items in Ireland. Ideas for Education is an offshoot of Lennox and designs, manufactures and exports items of science teaching equipment. A moulded acrylic safety screen from Shaws sells at £18, a huge saving on other models. An electrolysis cell, designed by an Irish teacher, uses a standard slide box as a container and can be used on an overhead projector. Ammeters and voltmeters assembled locally retail at £21 compared to around £30 for the imported ones. These are a few examples of what is being done in a very small market - in larger countries there would be economies of scale. Most of these items could be made up in a school but unit costs of parts would be higher and the finished product would probably lack the finish and robustness of a manufactured item.

ECONOMISING ON CHEMICALS

The same steps for reducing costs can be done for chemicals as for apparatus i.e. substitution with local or waste materials, manufacture from local materials, importation in bulk and repackaging , or direct importation. However, I just want to look here at some ideas for reducing chemical costs drawn mainly from the first category.

(a) Local Sources of Materials

We should emphasise the chemistry of readily available materials - in the garden, kitchen, bathroom, garage or medicine cabinet. Many chemicals are available for other purposes which can be used in the laboratory. This means looking at experiments and asking 'Can this chemical be obtained locally or substituted by another cheaper one ? 'Can I illustrate these principles by using readily available chemicals ?' Instead of buying in reagent grade sodium carbonate from a laboratory supplier why not use domestic washing soda crystals ? This can be heated to produce anhydrous sodium carbonate and for most laboratory purposes would be adequate. Fertilisers can provide supplies of ammonium salts and urea. Bleach can be used as an oxidising agent, for iodine-thiosulphate titrations and for making chlorine water (by acidification). Many chemicals are available in fairly pure grades from chemists, agricultural suppliers, hardware shops, factories, etc. Chemistry teachers need to be encouraged to go out and find out what they can get locally before buying in chemicals or worse, not doing experiments at all for lack of chemicals.

(b) Substitution by Cheaper Chemicals, Grades or Amounts

When chemicals have to be bought we need to decide which grade to buy, which salt to purchase and whether an acceptable, cheaper substitute is available. For use as solvents industrial meths or petrol or paraffin or turpentine may be acceptable. For most laboratory purposes at school Analar reagents are a luxury and reagent or technical grades are quite acceptable. The quantities are also important and here there is an advantage in bulk buying and repackaging into school-sized amounts e.g. buying 1 kg to supply 10 schools with 100g each, rather than buying 10 x 100g separately. Teachers are in a 'Catch 22' situation when ordering from catalogues -

small amounts suitable for a year's supply cost more per unit amount than larger amounts, but these may hang about for years before being used up and require more expenditure initially. Just this summer teachers on a course were asking us to give them an opportunity to make-up solutions and repackage smaller quantities of chemicals, which otherwise they wouldn't be able to afford.
If you want a metal salt to illustrate the chemistry of an element its worth checking the relative costs per mole of metal to see which is cheaper. Appendix 2 gives some examples of cost evaluations.

(c) Reducing the Quantities

Too often teachers and students follow recipes slavishly without thinking about what they're doing -'Do I need that much product ?' 'Will the reaction work for smaller amounts or lower concentrations ?' We need to think small to save money - work in test-tubes instead of flasks, do spot-tests instead of test-tube experiments, work at 1/10 scale or 1/10 concentration or less. As a bonus smaller quantities are safer and everyone can do an experiment previously confined to a teacher demonstration, without extra cost. Many titrations work well at 0.1M or even 0.01M - each power of 10 reduces costs by 10 and makes chemicals go 10x further. Even reducing bench reagents from 2M to 1M or 0.5M makes chemicals go 2 or 4x further.* In making gases use boiling tubes for collection as routine, rather than gas jars. 10g of marble chips (limestone) - from a local quarry, roadworks or cemetary, of course - will make over 2L of carbon dioxide or about 40 boiling tubes ! *In Copenhagen bench reagents were 4M!

(d) Recycling and Recovery of Chemicals

Apart from the pollution it causes, pouring chemicals away down the sink is money down the drain. We need to think carefully about what can be recovered economically and redesign experiments with recycling in mind. Some experiments could involve recovery of chemicals used in other experiments or by other classes. Otherwise the teacher is left with the job of recovery or some pupils might be eager to help after school. If solutions are dilute it's probably not worth recovering the chemicals unless they are very valuable. Likewise if too many chemicals are mixed up it's not worth trying to separate them. For metal compounds precipitation or crystallisation are possible approaches. For organic compounds distillation, solvent extraction

and fractional crystallisation can be tried. Even an impure product may be useful – for some undemanding experiment later on or as an analysis problem for a more advanced class. If most chemicals have to be imported and are obtained after a lengthy process, it makes sense to recover and recycle as much as possible. There are plenty of ideas in the literature in this area.

CONCLUSION

Any improvement in science teaching is useless unless it reaches the teachers in schools. Changing teacher's attitudes and improving their skills and personal confidence are vital if science teaching is to be improved. International workshops or conferences of 'experts' achieve nothing unless the results percolate back to the grass roots. Reducing the cost of science teaching should start with basic equipment and chemicals first, before moving on to sophisticated apparatus. Teachers should be encouraged and helped to become improvisers and utilisers of local materials. UNESCO could profitably produce at regular intervals worksheets for making equipment or chemicals, drawn from many countries through a network of rapporteurs.

BIBLIOGRAPHY ON LOW-COST SCIENCE TEACHING EQUIPMENT

a) Books:

'New UNESCO Source Book For Science Teaching' (1973) UNESCO

'Handbook For Science Teachers' (1980) UNESCO

'School Science Laboratories' Archenhold, Jenkins, Wood-Robinson, Murray (1978)

'Making Science Laboratory Equipment' X.F. Carelse, Wiley (1983)

b) Reports:

'Survey of Science Education Equipment - local production centres' ICASE

'Asian Symposium on Low-Cost Equipment' (Philippine Seminar 1979) ICASE

'Low-Cost Science Teaching Equipment' (Report of Regional Seminar in the Bahamas, 1976) Commonwealth Secretariat (ICASE)

'Low-Cost Science Teaching Equipment' (Report of Regional Seminar in Papua and New Guinea, 1979) Commonwealth Secretariat (ICASE)

'Development and production of School Science Equipment' 1979 Commonwealth Secretariat (ICASE)

'A Laboratory Manual For Low-Budget Teaching of Chemistry', Volume I IUPAC, CTC (Madras Workshop, 1981)

c) Periodicals:

Descriptions of low-cost equipment are frequently found in Science teaching journals e.g. J. Chemical Education, School Science Review, Education in Chemistry, Science Teacher, J. College Science Teaching etc.

APPENDIX 1

A. CHEAP PIPETTE FILLERS USING SQUEEZY DETERGENT BOTTLES

Source: School Science Review March 1983

Instructions: Materials required - one squeezy detergent bottle or similar container (1 pint, 568mL size); one-hole rubber bung to fit neck of bottle.

a) fit pipette with rubber bung so that tip of pipette is just above bottom of bottle when inserted . N.B. use a cork borer to insert the pipette safely.

b) remove plastic stopper from squeezy bottle and wash out well. Fill bottle with reagent after rinsing out with a little reagent first. Label bottle clealy with its contents.

c) insert the pipette and stopper to give a tight fit. Fill the pipette by squeezing the bottle gently. Stop the reagent rising when it is above the mark by putting your finger over the end of the pipette and releasing the pressure on the bottle.

d) with a finger over the end, remove the pipette and run out the reagent in the normal way. Restopper the squeezy bottle with a bung or its original stopper until needed again.

cost: one one-hole and one solid rubber bung

(a)

(b)

APPENDIX 1 contd.

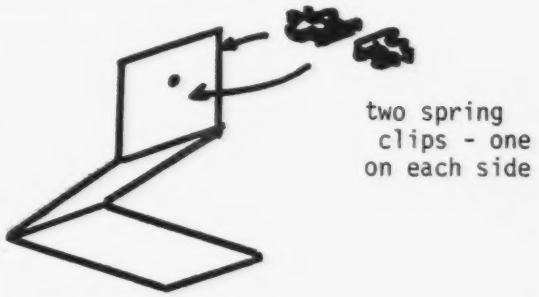
B. A VERSATILE STAND FOR CHEMICAL EXPERIMENTS

Source: P.E.Childs -adapted from ideas seen in catalogues

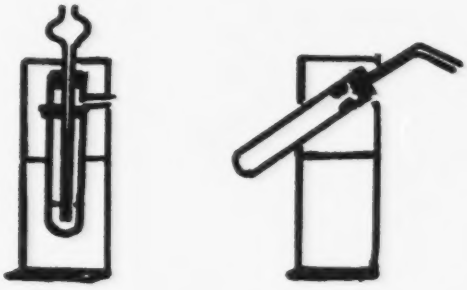
Materials: metal sheet 12" x 3" (30cm x 7.5cm) - mild steel, galvanised sgeet or aluminium alloy sheet
two spring clips (plastic-coated or plain) - size to suit testtubes being used (3/4" or less)
heat-proof metal paint for finishing

Instructions: cut a piece of metal sheet 12" x 3" (not critical),round off the edges and then bend to shape according to the plan below. The base is about $4\frac{7}{8}$"-5", and the sloping piece about the same - the dimensions are not critical and can be modified to suit different uses, e.g. for a burette stand the vertical piece would be larger to accommodate two clips.
Drill a small hole in the upright to take a small bolt or metal rivet and fasten a spring clip on each side of the upright - both sides of the stand can be used for different purposes now. The angle of the clips can be altered if one wants to heat a testtube at an angle. Finish by painting with heat-ressstant paint to rust-proof the metal. The stand should be painted white for preference.

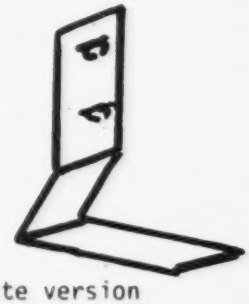
Metal sheet



Finished stand



Two uses



Burette version

APPENDIX 2 SOME EXAMPLES OF COST EVALUATIONS OF CHEMICALS

A. Cost of making up indicators (P.E.Childs Sch.Sc.Rev. 58(204)477-479 1977)

The cost of making up phenolphthalein and bromothymol blue indicators was compared with the cost of buying in ready-made solutions. The results are shown in the table below.

		Size	Cost/£	Cost per dm^3/£
Bromothymol blue 0.04%	1.	$100cm^3$	0.62	6.20
	2.	$2.5dm^3$	5.89	2.36
	3.	$1\ dm^3$	0.75	0.75
Phenolphthalein 1%	1.	$100cm^3$	0.66	6.60
	2.	$2.5dm^3$	5.81	2.32
	3.	$1\ dm^3$	2.19	2.19

1. and 2. are prices of ready-made solutions and 3. is the cost of chemicals for making up 1 dm^3. The figures show clearly a) the disadvantage of buying in small amounts, b) the advantage in making up solutions oneself - slight in the case of phenolhthalein, marked in the case of bromothymol blue, c) the difference between alternative indicators.

I have a strong preference for the bromothymol class of acid-base indicators which have a yellow-blue colour change over the more commonly used phenolphthalein (colourless - pink). They are more colourful and more students can see the colour change than can shades of red - colour blindness is a significant problem in the population but very few are yellow-blue blind, whereas yellow/orange/red changes present problems to more.

B. Fehling's solutions ("Chemistry in Action!", 6,25 1982)

The cost of buying in Fehling's solution A and B was compared with the cost of making up solutions according to two recipes - the traditional one and a new one given by D. Mansfield in Sch.Sc.Rev. 63(222)117 1981. The results are compared below.

		D.I.Y. solutions	
	Bought-in	Old recipe	New recipe
Fehling's A	£1.68	£0.51	£0.51
Fehling's B	£2.94	£3.04	£1.15

The advantage of making up the solutions oneself can be seen particularly for solution A and for solution B using the new recipe. The prices are per dm^3.

APPENDIX 2 contd.

C. Costs of metal salts

Often we want a salt of a metal for doing tests on the metal or making up a solution and in the catalogue there are several possibilities listed for each metal. Which do we buy? If we need a particular salt (anion) then the Problem is solved or if we know that one salt is unstable and cannot be kept. But usually out choice is just random and we can end up buying the most expensive salt out of ignorance. I have computed the costs per mole of metal for zinc salts below as an illustration for both GPR and Analar grades, for 500g lots. Smaller lots will cost more per g and larger lots will cost less per g.

			G.P.R.		Analar reagent	
Compound & formula	Mol.mass /g	% metal	Cost/£ (500g)	Cost per mole metal/£	Cost/£ (500g)	Cost per mole metal/£
Zinc Zn	65.4	100	4.09	0.54	4.82	0.63
Zinc acetate $(CH_3COO)_2Zn.2H_2O$	219.5	29.8	7.04	3.09	7.92	3.48
Zinc bromide $ZnBr_2$	225.2	29.0	7.81	3.52	-	-
Zinc chloride $ZnCl_2$	136.3	48.0	2.77	0.76	5.57	1.52
Zinc nitrate $Zn(NO_3)_2.6H_2O$	297.5	22.0	5.89	3.50	8.75	5.20
Zinc oxide ZnO	81.4	80.3	2.17	0.35	3.19	0.52
Zinc sulphate $ZnSO_4.7H_2O$	287.5	22.8	3.00	1.73	3.47	2.00
Copper(II) sulphate $CuSO_4.5H_2O$	249.7	25.5	3.63	1.81	4.75	2.37
Copper(II) sulphate $CuSO_4$	159.6	39.8	8.51	2.71	-	-

What conclusions can we draw? For zinc compounds, the cost per mole of zinc increases in the order: oxide < chloride < sulphate < acetate < nitrate ≃ bromide for G.P.R. grades. Analar grades are 15-100% more expensive. The cheapest soluble salt is zinc chloride but it is deliquescent and zinc sulphate is probably the best buy.

Comparing hydrated and anhydrous copper(II) sulphate it is obvious that you pay a lot for having the chemical company heat the crystals to drive off water! The best solution is to buy G.P.R. hydrated copper(II) sulphate and make your own anhydrous salt as required.

REDUCING THE COST OF SCIENCE TEACHING APPARATUS

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Innovation in apparatus development is often centered around designing apparatus to do new jobs. From the point of view of a commercial equipment supplier, there is considerable incentive to lead the field by producing ever more sophisticated pieces of equipment. There is less incentive to devote development resources to existing equipment and in particular to reduce its cost. In this field the onus is on us to set design standards.

The field of electronic instrumentation is one in which the need for user direction is very clear. Modern measuring systems for use in education are often too sophisticated. Their internal circuitry is complicated and obscures their method of operation. This complexity reduces reliability and makes servicing much more difficult.

It is helpful to break down the systems that we use for measuring into smaller parts.

Diagram 1, page 47.

The experimenter wants to know something about his experiment. The measuring system conveys this information to him. The input interface converts perhaps a chemical signal usually into an electrical one, which is then processed. The output interface - often a moving coil meter - converts an electrical signal into something that the experimenter can read.

A colorimeter has some sort of light sensitive component as the input interface, an electrical processing circuit and an output meter. A pH meter has a pH probe, a current amplifier and an output meter.

There is a great temptation when starting the design of the measuring system to plunge in at the deep end - straight into the hardware. In practice, one is better advised to look outside the system - at the experiment and the experimenter and even the lab in which the experiment is to be performed. I have here two examples from physics, of pieces of apparatus

where the concept of the problem changed considerably during this first stage of development.

The first is a current balance. The force on a current carrying conductor is difficult to measure - in some situations you want to measure as low as 0.01 gwt. Physicists want a moderate degree of accuracy and a fair number of current balance designs have been produced. The simple ones are too crude - the accuracy is much below what one wants; the sophisticated ones are too expensive. A better solution works in conjunction with a top pan balance and uses the measuring system that one already has. It is worth looking around to see what is available.

The second item is a joulemeter. For teaching calorimetry we have in Britain used re-wound electromechanical electricity meters. They measure the electrical energy supplied from an AC source to a heater. These electromechanical meters are expensive - around 150 US dollars - and various slightly cheaper electronic joulemeters have been produced. However, they are only slightly cheaper (around 120 dollars) but they are superb instruments. A frequency response from DC to several kilohertz means that you can use them in AC theory. They will work down to zero volts input to enable you to measure the energy stored in a capacitor. They indicate over enthusiasm in the part of the designer who thought "what if they could do this, and this and this".

Again a more realistic solution is possible. It only works around 50 Hz AC (but that is all you need) it only works between 8 and 16 volts (but that is all you need) it is only accurate to within 10% (but that is all you need) it only costs 15 dollars (that is just what you need). If you reduce the device specifications to the minimum, something that you could not afford often becomes possible.

I think that it might be worth looking in detail at one particular piece of apparatus - the pH meter. I have here to rely on information given to me by my chemist friends. I am a physicist, you may have guessed. If you ask me too many of the wrong sort of questions my background will very quickly become apparent.

The first thing that we notice with pH measurement is that our standards have a limited accuracy. We cannot expect buffer solutions to have an accuracy better than ± 0.02 or thereabouts, so we can't expect our measurements to have greater accuracy than this. It is senseless to design the apparatus with greater accuracy.

Then we have operator limitations. A typical pH probe may take several minutes to reach equilibrium. Will the operator wait that long or will he wait until the reading seems to have stabilised - within 10 to 15 seconds? Here you may introduce additional errors as great or greater than those of the buffer solutions. And anyway, most pH measurements are only needed to an accuracy of one decimal place. All right, there may be occasions when greater accuracy is called for, but there is no need to design all your meters to have the higher accuracy.

Next the input interface. pH probes are something of a problem. Glass electrodes in particular are unreliable. There is little point in designing a meter that will work with a perfect probe when most of the probes that one has in the labs are very different. We need to see what real probes are like.

Diagram 2, page 47.

Line 1 on this diagram shows what an ideal glass electrode combined probe does. The output is proportional to the pH. It is zero when the pH is 7. Real probes have varying offsets. Most of these variations are small lines (2) and (3). We can correct for these by adding or subtracting this offset. This is what the "set buffer" control does on most pH meters. Sometimes the offset is large - line 4 - several hundred millivolts. We can correct for it in the same way.

Differences in slope are rarer. Probes with glass electrodes that exhibit this are often ones that have been allowed to dry out. As well as the differences in slope, they also have readings that drift with time. For practical purposes these probes are unuseable. The pH meter may incorporate a "slope" control. This requires calibration every time that the meter is used. Here you have the experimenter effect. As the

instrument gets more complicated to use, the operator accuracy reduces. What starts out by aiming to be an improvement to reduce one sort of error, increases another sort.

The other characteristic of pH electrodes which is important is the current that can be drawn. It is limited by polarisation effects. A good glass electrode probe will supply getting on for 1 nA. As they get worse, the current gets less, the probe becoming unuseable when this current gets as low as 0.05 nA. Other forms of electrode have larger contact areas and can supply larger currents.

All these constraints affect the processing circuit. For the circuits that I have here, I have used a 081 operational amplifier. The cost in Britain is low - around 25p (i.e. about 3 for a dollar). The input bias current is typically 0.03 nA.

We have yet to consider processing circuits and output interface but let us do that with reference to some practical circuits.

Firstly the voltage follower. It produces an output that is equal to the input voltage and draws only the input bias current from the source. Here is a simple millivoltmeter.

Diagram 3, page 47.

If you want a circuit for measuring cell emf's then this will as it stands.

If you want to turn this into a pH meter, then the easiest way is to put a new scale over the old meter. I am assuming that the meter that you are using here is a standard lab item that you connect to the mV meter when you want to make such measurements. Having a moveable scale on the meter allows you to put it in an appropriate position for the particular probe that you are using but is rather a mechanical complexity. Much easier and not much more expensive is to use a potentiometer to provide an offset potential difference that you can adjust.

Diagram 4, page 48.

The voltmeter needs to be scaled assuming the standard slope. The "set buffer" control allows a variable offset which can be adjusted to suit the probe.

Sometimes it is inconvenient to calibrate the meter. If we want to be able to use any meter, let us have an electronic scaling circuit which will do the calibration. For an ideal probe, the output changes by 420 mV when the pH changes by 7. If we have a circuit that multiplies by 7/4.2, then when the input changes by 420 mV, the output will change by 700 mV for a change of pH of 7. If we add an offset to that then pH is the meter reading multiplied by ten. This is the arrangement that I have here. It needs a meter that will go up to 1.4 V representing pH 14.

Diagram 5, page 48.

Those who are more familiar with operational amplifier circuits may well wonder at the omission of mention of the offset null potentiometer. You don't need it. In pH measurements the "set buffer" control can compensate nearly enough for the input offsets that occur in the integrated circuit. In mV measurements you can use the offset null you already have - on the front of the moving coil galvanometer.

I haven't time to extol the virtues of digital meters. Most of them originate outside Britain. And they are rapidly becoming cheaper than moving coil meters. Not only can their basic cost be cheaper but the incremental cost in many areas can be cheaper for digital meters because they need fewer intermediate shunts and multipliers for the same resolution. We should be looking for ways in which we can add on simple circuits like that of Diagram 5.

Both the pH meters I have described so far use a meter as the output interface. This may be a significant cost deterrent. The potentiometer method for measuring emf's is often found in physics courses.

Diagram 6, page 48.

We can replace the galvanometer with the operational amplifier which is much more sensitive and draws far less current from the unknown emf.

Diagram 7, page 48.

For clarity, the supply lines to the operational amplifier are not shown. If the potential at the non inverting input is greater than the potential at the inverting input, then the output of the operational amplifier will be high. If the potential at the non inverting input is less than the potential at the inverting input, the output will be low. A light emitting diode can indicate the state of the output. As the slider of the potentiometer is moved from low to high, at some point, the light emitting diode will turn off. At this point, the potentials are equal. If the potentiometer is appropriately scaled then the reading may be made directly in mV or pH.

This isn't a complete circuit for a practical meter. We need to modify it to measure negative potentials and to provide a variable offset as in Diagram 8.

Diagram 8, page 49.

This circuit can easily be accurate to 1 decimal place of pH or a couple of mV. The component cost is about two dollars.

Let us return to the commercial world for a few moments to see how far we have gone. Here is a circuit diagram for a pH attachment for a digital panel meter (Diagram 9). It is an expensive and sophisticated design. But does it need to be as complicated as that? There seems to be a fair amount of redundancy in the circuit. It uses one stage as a follower to get a high input impedance and the next stage as an inverting amplifier to get that gain of 7/4.2 that we mentioned. In fact it does little more than this circuit of Diagram 5.

But this circuit feeds into a digital panel meter module that has an input bias current of 0.001 nA which is compatible with our electrodes anyway. So how can we use this?

We make our digital meter a factor of 6 less sensitive so that an input change of 420 mV causes the reading to change by 70 mV. This means adding two resistors to the meter module. We add the offset potentiometer and get this as the final circuit.

Diagram 10, page 49.

This circuit is cheaper, easier to set up, just as accurate and more reliable.

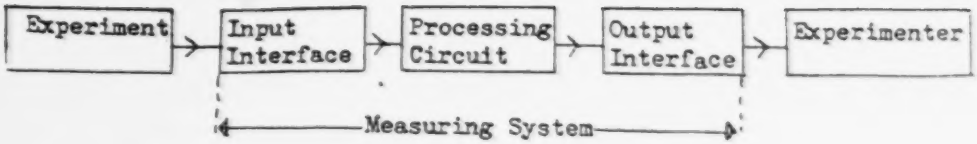


Diagram 1

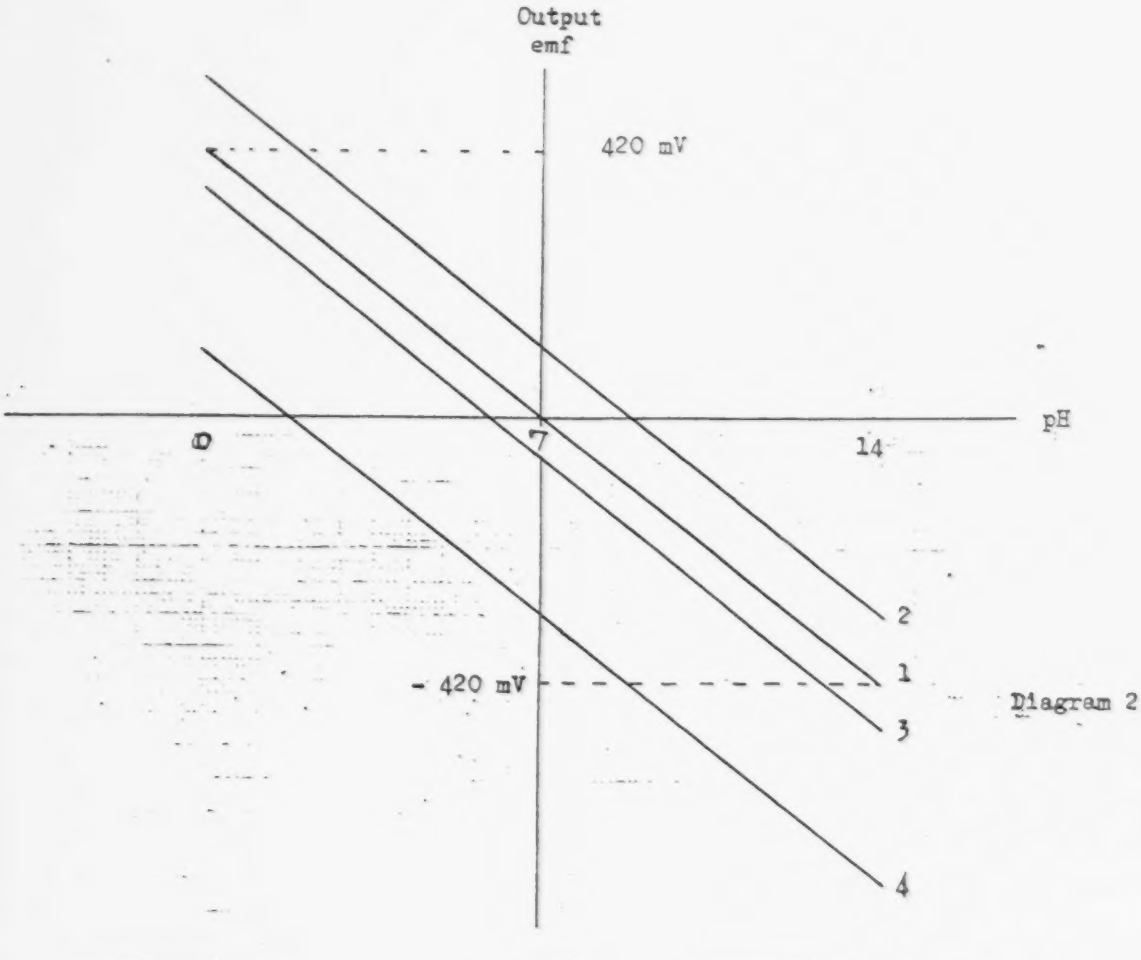


Diagram 2

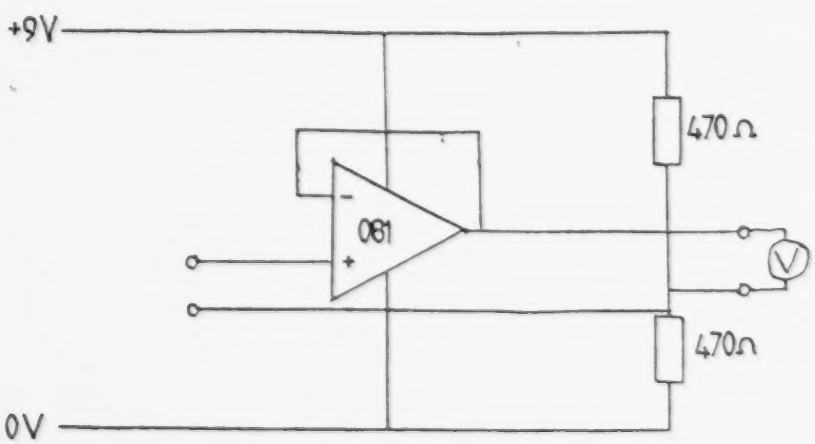


Diagram 3

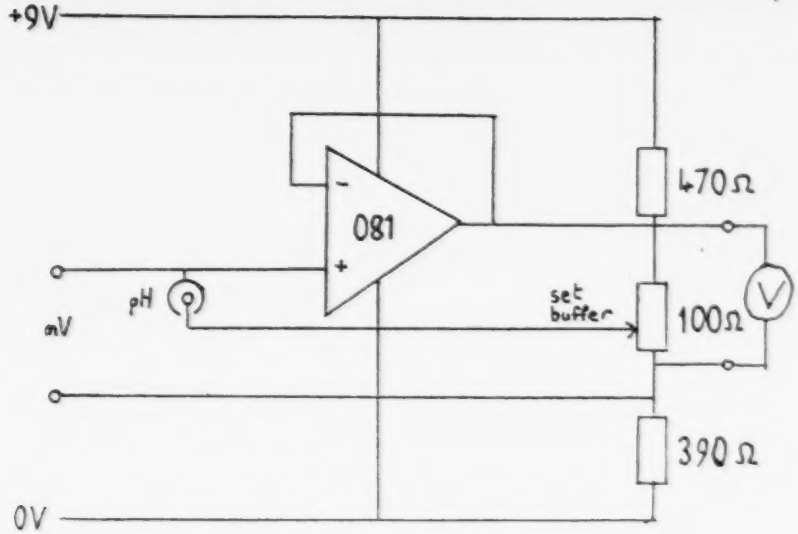


Diagram 4

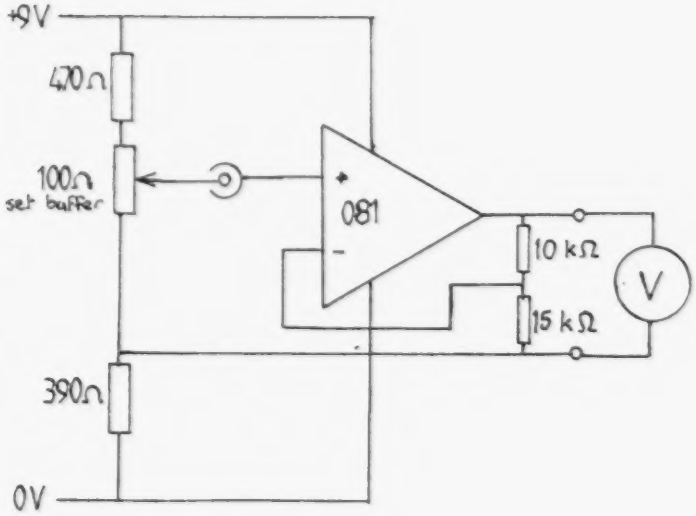
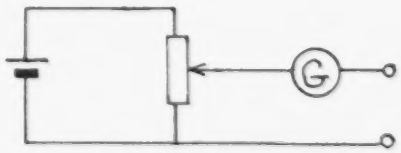


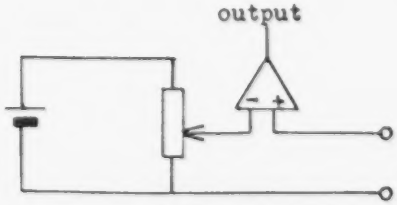
Diagram 5



connect to unknown emf

scaled potentiometer

Diagram 6



connect to unknown emf

scaled potentiometer

Diagram 7

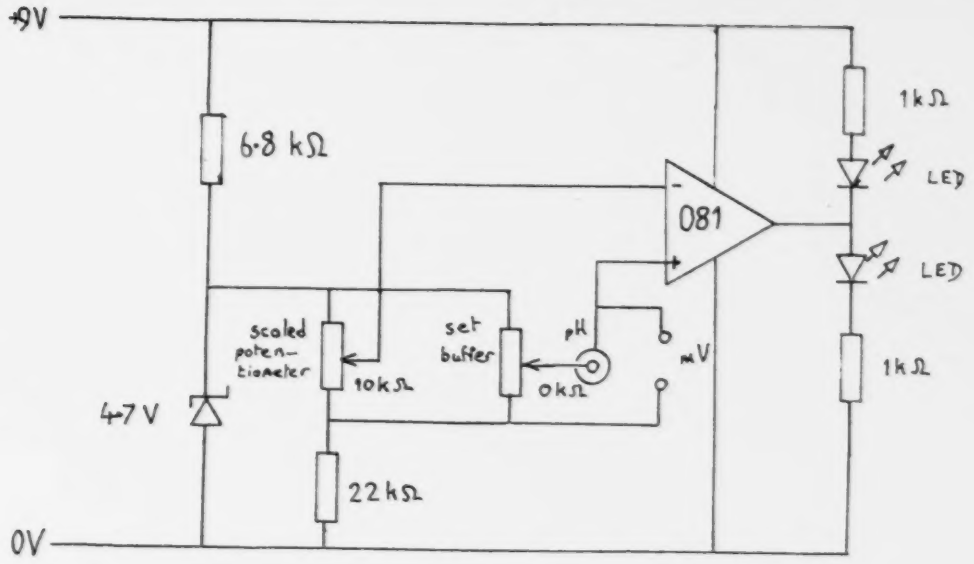


Diagram 8

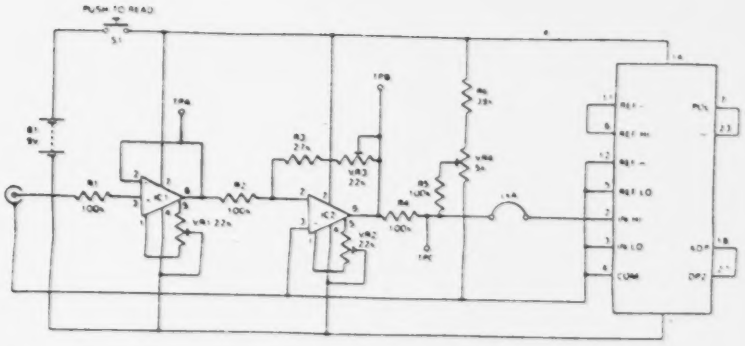
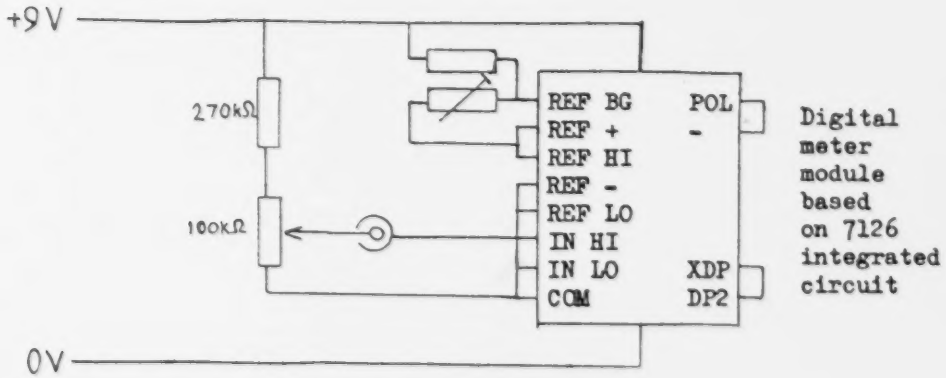


Diagram 9



Digital meter module based on 7126 integrated circuit

Diagram 10

LOW-COST APPARATUS - A PHYSICIST'S VIEW

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The paper looks at the principal ways in which savings can be made in locally-produced apparatus without disregarding the user's safety, and makes suggestions regarding further work that might be considered.

Much effort was spent in the UK, and elsewhere, in the early 1960s producing robust low-cost equipment for the Nuffield projects. Manufacturers co-operated enthusiastically, for it increased their range of products and the large ready market ensured good sales and good profits. But those who bought then have little to complain about - most of what they bought is still in regular use today, 20 years later. However, as demand dwindled and inflation struck, prices soared at greater than the inflation rate - indeed a cathode ray oscilloscope for class use which cost less than £20 in 1965 would cost £150 today. Sadly, that CRO is no longer made because it pays the manufacturer to concentrate his efforts on a more expensive model which appeals to a wider market. It was because schools were being forced to consider more expensive and often less convenient equipment with facilities that were not required, that I first looked at the possibilities of producing cheaper varieties for school use.

A lot of what I have to say applies to all forms of measuring and demonstration equipment, but I shall concentrate on those which essentially depend on an electronic circuit. If I were to draw a block diagram of that equipment, then the heart of it would be the electronics. That must have a power supply, a means of displaying information or passing its output to the outside world and a means of accepting input information via suitable connections.

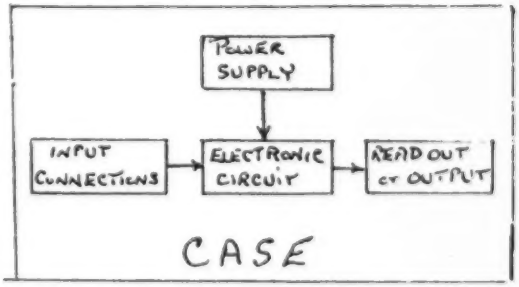

Fig 1

In addition, all the bits need to be supported or protected, i.e. they are put in a case (Fig. 1). When costs are analysed, the first notable result is that the selling price is about five times the cost of the 'bits' to the manufacturer. The difference represents labour and development costs, packaging and delivery charges, advertising and instructional material, and profit. Clearly a considerable saving can be made simply by providing the labour and doing without the packaging etc. It is not unusual for the 'bits' to cost more than the commercial concern pays so that the saving may be 60%. Any further savings demand simplification and improvisation and possibly a reduced specification.

Analysis of the 'bits' price usually reveals that the most important contributors to cost are the power supply and the case. The former uses a relatively expensive interleaved transformer with associated safety measures such as fusing, cable clamps, grommets. The case, usually of steel or a thick well-strengthened plastic moulding, has to be substantial in order to carry the weight of the transformer and allow the electronics to be installed away from the heat and the fields around it. My first economies were, therefore, to dispense with the transformer and the necessary safety measures associated with a mains supply, and design circuits to accept low voltage a.c. inputs from a separate multitap transformer using 4 mm plug leads. This step raises an important issue. In asking our pupils to use cheaper equipment or home-made equipment, we must not increase the danger to the operator by skimping safety measures. The multitap transformer is a 'standard' item in our laboratories and all the necessary safety measures that the law demands regarding mains supplies are within the transformer box and there is no need to repeat these if the low-cost item is designed to run from a low voltage a.c. input.

The low voltage a.c. supply is rectified within the instrument by a bridge rectifier whose output is regulated by an I.C. regulator. This requires only one electrolytic capacitor. It is worth pointing out that a power supply of this type also works with a source of d.c. Most modern

electronic equipment can be driven from an a.c. supply in the range 8-12V at a current less than 1A, and I do urge you - strongly - to consider this method of supplying power as a standard, especially in view of the fact that dry batteries can also be used successfully if the current demand is not large. And now, having got rid of the transformer, a simpler and smaller box - of plastic - can be used, or indeed the box may be dispensed with altogether in some instances.

The next level of economy relates to the read-out. Frequently, this is a meter and though circuits can often be designed to use a relatively cheap commercial instrument, savings can be made if even this can be eliminated. That could be accomplished by supplying output connections for a meter of specified range from the laboratory stock, but now we have to mention what I shall call the Frustration Factor - the irritation that arises when the user has to gather several items and interconnect them before he can proceed. Only the user can judge when economic gain is out-weighed by the frustration factor. But if some integral 'meter' read-out is essential, then, with a little sacrifice in accuracy, it is possible to use an operational amplifier, LEDs and a calibrated potentiometer as a replacement for a pointer instrument.

That leaves only the input connections and the electronics from which savings can be made. Whether or not that is a viable possibility depends on factors like accuracy and sensitivity and stability. Savings are not likely to be large and may involve an increase in the frustration factor if frequent external adjustments are necessary.

Bearing all these points in mind, I do not think it is difficult to reduce the cost of a piece of acceptable apparatus to something of the order of 1/5th (20%) of a manufacturer's price.

I now wish to suggest another direction to which you might turn your thoughts. If operational amplifiers are used in linear circuitry, i.e. circuits in which voltage/current values may vary continuously, the accuracy of the output will depend

on the tolerance of the components used - and low tolerance components are more expensive. Elimination of temperature effects in the input offsets may complicate the circuitry - and the need for a centre-tapped power supply is another disadvantage. Modern electronic measuring systems now generally use digital methods in preference to linear or analogue methods. The functioning of a digital system relies only on whether a voltage is above a certain value or below another, i.e. whether it is high or low, whereas an analogue system depends on the actual value of the voltage. Digital systems are thus more accurate in operation than analogue systems. In addition, only a single power supply is required, the circuits are less prone to 'noise' troubles and drift effects. Developments in the art of fabricating integrated circuits have made it possible to produce all the necessary electronics complete on one chip so that all it is necessary to provide is the power supply - and sometimes, the read-out. In the rather cleaner atmosphere of a physics laboratory, even the case may not be vital.

But that is not all. Fifteen years ago, calculators appeared on the market - and those which sold then for £50+ now cost less than 1/3rd of that, in spite of inflation. Today, there are microcomputers available for about £100, and microprocessor measuring systems at a similar price. Perhaps the future lies in developing interface circuits which can be used with a simple microcomputer - or with dedicated microprocessor systems.

The first advertisement for this workshop stated that it was to bring European <u>scientists</u> together... to suggest further work in the field of locally-produced apparatus for...education. I admire the work you are trying to do - yet I feel disappointed that it is the chemists alone who are doing it and not with the physicists. In the UK and at the level at which I teach, the opportunities for cost-cutting in Chemistry are few. The range in Physics is much wider. There we have a need for frequency meters and counters, for very high impedance electrometers/DC amplifiers, for waveform generators, for amplifiers, for clocks operated

by external stimuli, for low voltage power supplies, for multi-range meters - even for apparatus just to teach the principles of electronics. Dare I suggest that your efforts would be of the greatest benefit to the greatest number if you were to widen your terms of reference? Can you not become the group concerned with Locally-produced Equipment for Science Education?

OPERATIONAL AMPLIFIERS

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The paper examines the properties of an 'ideal' operational amplifier and how it might be used under non-saturated and saturated conditions. The ways in which a 'real' operational amplifier fails to match the 'ideal' behaviour are mentioned with some indications to show how to overcome them.

The operational amplifier is a circuit which can be used to perform the mathematical operations of addition (or subtraction), multiplication (or division) by a constant, and integration (or differentiation). It is, however, a much more useful device than that brief definition indicates, for it can also be used as a comparator or switch, and hence as an oscillator generating various waveforms.

POWER SUPPLIES

Generally, the op.amp. is supplied from a d.c. source with a centre tap whose potential is referred to as 0 volts, the amplifier terminals being connected to $+V_s$ and $-V_s$ (Fig. 1). It has two inputs (labelled + and −) and one output connection. In the ideal case and with potentials V_1 and V_2 applied to the inputs (Fig. 1), the output voltage, V_o, is given by

$$V_o = A(V_2 - V_1)$$

where A is called the open loop gain. Note that:

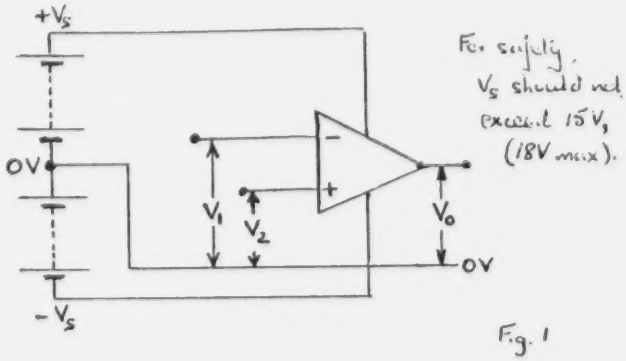


Fig. 1

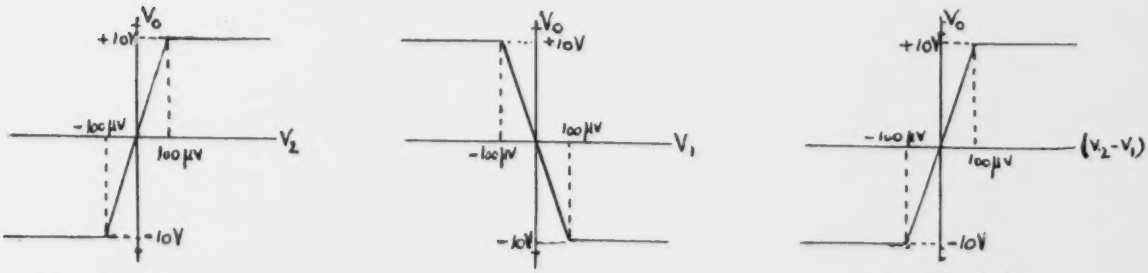
(a) if $V_1 = 0$, then $V_o = AV_2$; V_o and V_2 have the same signs and this input (+) is called the non-inverting input, i.e. when V_2 is positive relative to 0V, V_o is also positive.

(b) if $V_2 = 0$, then $V_o = -AV_1$; V_o and V_1 have opposite signs and this input (−) is called the inverting input, i.e. when V_1 is positive relative to 0V, V_o is negative.

(c) if $V_1 \neq 0$ and $V_2 \neq 0$, the circuit is referred to as a differential amplifier.

The "Ideal" Operational Amplifier

The open loop gain, A, is usually about 10^5 (100 dB) - the higher it is, the better - and V_o can swing to within about 1V of $+V_s$ and $-V_s$. Thus, if the output voltage, V_o, is plotted as a function of input voltage, the graphs will be as in fig. 2 for an amplifier with $A = 10^5$ operated from a supply of ± 12V. For convenience, it has been assumed to saturate at ± 10V.



(a) $V_1 = 0$ (b) $V_2 = 0$ (c) $V_1 \neq 0, V_2 \neq 0$

Fig. 2

Thus, if the amplifier is NOT in one of its saturated states, the p.d between the input terminals can never exceed 100 μV ($10/10^5 = 10^{-4}$V). If one of those terminals is at 0V, then, because a p.d. of 100 μV is negligible, the other terminal of the op. amp. is referred to as a 'virtual earth', i.e. its potential is virtually 0V. In addition, the resistance between the input terminals is high (in excess of 1MΩ) so that, under non-saturated conditions, the input current does not exceed 100 pA ($10^{-4}/10^6 = 10^{-10}$A), and that too is negligible. Thus, provided the amplifier is <u>not</u> saturated, the p.d. required to operate it, and the current flowing into it as a result, are negligible.

Feedback - Basic Circuits

Of course, the amplifier could not be used in this simple way; the slightest p.d. between the input terminals would cause it to saturate. To use it, feedback from the output to the input must be applied in such a way that any change in the output voltage counters the input change that caused it. This is called Negative Feedback and the inverting input (-) has to be used by one of the following methods.

A. The Inverting Amplifier

If the amplifier is not saturated, E is a virtual earth (Fig. 3) i.e. potential at E, $V_e = 0$. V_{in} causes an input current I given by

$$V_{in} = IR_1 \quad (\text{p.d. across } R_1 = V_{in})$$

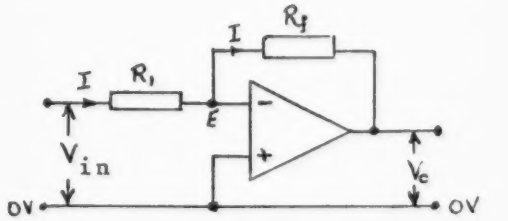


Fig. 3

As the current into the amplifier is zero, the current flowing in the feedback resistance, R_f, is also I and so (V_o being negative)

$$-V_o = IR_f \quad (\text{p.d. across } R_f = 0-(-V_o) = V_o)$$

The gain of the circuit (referred to as the closed loop gain A_{CL}) is $\underline{V_o/V_{in} = -R_f/R_1}$. Thus the gain depends only on the component values and not on the op. amp. characteristics, provided the open loop gain is very high, the input resistance is large and the op. amp. is not saturated. The input resistance of this circuit (V_{in}/I) is equal to R_1.

B. The Non-inverting Amplifier

Here (Fig. 4), the voltages at the - and the + inputs are virtually identical but not zero. Thus $I = V_o/(R_1 + R_f)$ and since $V_E = IR_1$

$$V = V_o \cdot \frac{R_1}{R_1 + R_f} = V_{in}$$

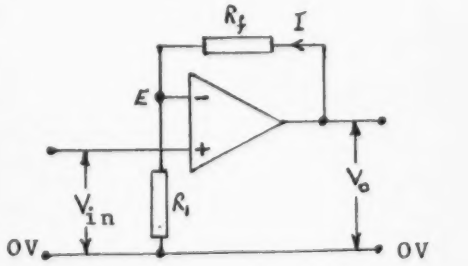


Fig. 4

$$\text{Closed loop gain } (A_{CL}) = \frac{V_o}{V_i} = \frac{R_1+R_f}{R_1} = 1+\frac{R_f}{R_1}$$

The input resistance is high as the input current has a maximum value of about 100pA. [The input resistance $\approx \frac{A}{A_{CL}}$ x op. amp. input resistance].

In one important use of this circuit, R_f is made equal to zero, so that $A_{CL} = 1$. R_1 is then not necessary and the circuit is now as in Fig. 5. The circuit is now known as a 'voltage follower' because $V_o = V_{in}$ and it has the advantage that current may be drawn from it without 'any' being drawn from the source.

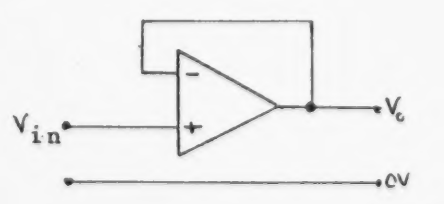


Fig. 5

C. The Differential Amplifier

Again, for non-saturated conditions, there is virtually no potential difference between the op.amp. inputs of the circuit of Fig. 6.

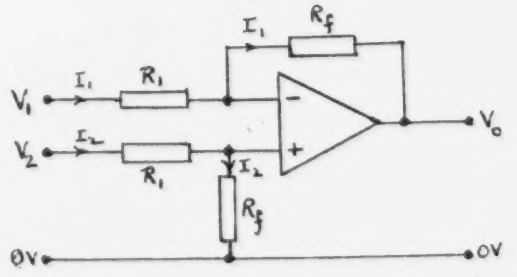


Fig. 6

At the + input, the potential is

$$\frac{R_f}{R_1 + R_f} V_2$$

At the -input, the potential is

$$\frac{R_f}{R_1 + R_f} (V_1 - V_o) + V_o$$

$$\therefore \frac{R_f}{R_1 + R_f} V_2 = \frac{R_f}{R_1 + R_f} V_1 + V_o \left(1 - \frac{R_f}{R_1 + R_f}\right)$$

which leads to $R_f(V_2 - V_1) = R_1 V_o$ and a closed loop gain

$$= \frac{V_o}{V_2 - V_1} = \frac{R_f}{R_1}$$

D. The Integrator

Using a capacitor as a feedback component produces a circuit which can perform integration with respect to time. E is a virtual earth and hence applying V_{in} to the input of the circuit causes a current I to flow through R (Fig. 7).

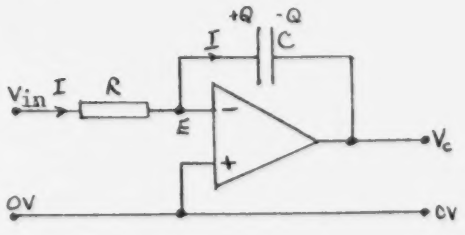


Fig. 7

None of this current enters the amplifier, so that C is charged by I and the voltage V_o must therefore fall (linearly if V_{in} is constant).

Since $V_{in} = IR$ and $V_o = -Q/C$ and $I = dQ/dt$, then $\frac{V_{in}}{R} = -C\frac{dV_o}{dt}$

Thus $V_o = -\frac{1}{CR}\int V_{in}.dt$

E. The Differentiator

In the circuit of Fig. 8, the op. amp. maintains E as a virtual earth so that current I flows to charge C.

$I = \frac{dQ}{dt} = C\frac{dV_{in}}{dt}$ and $-V_o = IR$

Hence $V_o = -CR\frac{dV_{in}}{dt}$

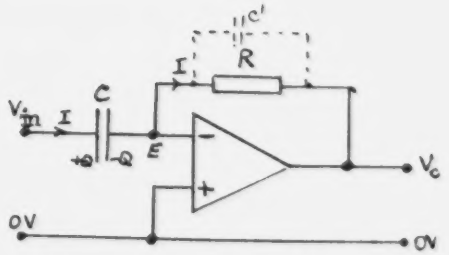


Fig. 8.

In practice, a small capacitor, C', is connected across R to reduce high frequency noise, because when differentiated, noise of frequency f, ($\alpha \sin 2\pi ft$), becomes amplified $2\pi f$ times ($\alpha 2\pi f \cos 2\pi ft$).

F. The Summing Amplifier

If an op. amp. is not saturated and its +input is at 0V, the existence of the virtual earth at E effectively isolates the feedback loop from the input circuit (Fig. 9). It will also effectively isolate one input from another. Thus, for Fig. 9,

$V_1 = I_1R_1$, $V_2 = I_2R_2$ and $V_o = -R_f(I_1 + I_2)$

Eliminating I_1 and I_2 gives:-

$$-V_o = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2$$

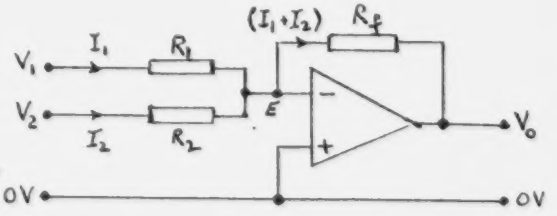


Fig. 9

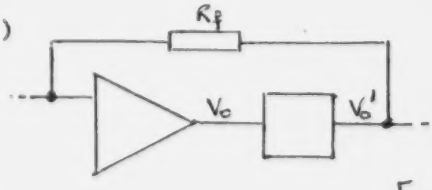


Fig. 10

The circuit multiplies V_1 and V_2 by constants and then adds the results. If all the resistances are equal, then $V_o = -(V_1 + V_2)$ and the circuit becomes an adder. Multiple inputs can also be used with the circuits of D and E above.

One other point regarding feedback is worthy of mention. The output of an op. amp. is sometimes fed to another circuit which has output V_o'. If the feedback loop is taken from the V_o' output (Fig. 10), then the relationships derived above apply to V_o' provided the feedback is negative, the op.amp. is not saturated and the open loop gain is still large enough for the p.d. at the input terminals to be negligible. This arrangement is particularly useful when a non-linear circuit is required to behave linearly.

OUTPUT RESISTANCE

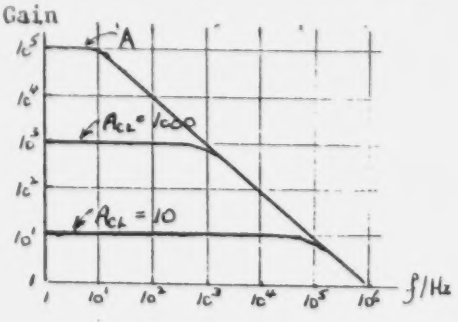
The output resistance of an op.amp. may be compared with the internal resistance of a cell; it causes the output voltage to fall when current is delivered. Ideally, an op. amp should have zero output resistance, but, in practice and without feedback, it is of the order of 100Ω. Of course, feedback tends to keep the output voltage fixed and so effectively reduces the output resistance. For an op. amp. with output resistance R_o and open loop gain A used in a circuit with closed loop gain, A_{CL}, the effective output resistance is of the order $R_o \cdot \frac{A_{CL}}{A}$ and is less than 1Ω in practice. However, this does not mean that currents of the order of amps may be taken from an op. amp.'s output; other considerations limit the current to about 10mA.

SOME DISADVANTAGES OF OP. AMPS.

A real op.amp does not quite behave in the idealised way described above.

1. Open Loop Gain, A

A is not independent of frequency. In order to achieve stability in operation, the op. amp. is constructed so that A falls off with frequency from $\sim 10^5$ at frequencies up to 10Hz to unity at $\sim 10^6$Hz. If such an op.amp. were used in a circuit with a closed loop gain of A_{CL}, the gain would remain essentially constant up to the frequency given by $f.A_{CL} \approx 10^6$Hz.



A is also a function of the supply voltage and of the current taken from the output, but these changes are relatively unimportant in most applications.

2. Common Mode Effects

The output voltage is actually given by $V_o = A(V_2 - V_1) + A'\left(\frac{V_1 + V_2}{2}\right)$, i.e. it depends also on the average or common mode voltage present at the inputs. A/A' is known as the common mode rejection ratio and is usually about 3×10^4 (90dB) so that $A' \simeq 3$. This effect is of no significance if $V_1 = 0$ or if $V_2 = 0$, for in those cases, V_o is still proportional to V_2 or to V_1.

but this condition does not apply to the non-inverting amplifier (B) and to the differential amplifier (C). In the case of the non-inverting amplifier, the feedback counters the effect and the error introduces is a small fraction of 1% $\left(\frac{100A'}{A}\right)$. In the differential amplifier, the error is larger $\left[\frac{100A'}{A}\left(\frac{V_2}{V_2-V_1}\right)\%\right]$ and indeed may easily exceed 10% if (V_2-V_1) is small with a high value of V_2.

3. Input Offset Voltage

Even if both the inputs of an op. amp. are at 0V, the output voltage will not be zero because of small mismatches within the integrated circuit. The input offset voltage is the input voltage equivalent to this output and it is usually about 1mV. This is enough to saturate the amplifier if there is no feedback. A means of compensating for this is usually provided (Fig. 11), and the manufacturer's literature should be consulted for the circuit required.

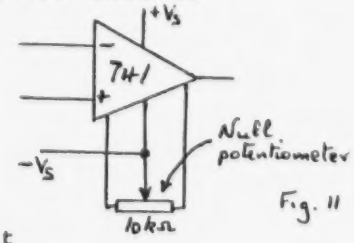


Fig. 11

4. Input Bias Current and Input Offset Current

Small currents flow into the amplifier via the input terminals. The mean value of these is called the input bias current ($\sim$100nA), and their difference the input offset current ($\sim$20nA). If the input bias current is comparable with the currents flowing in the input and feedback resistors, then the assumptions made in deriving the formulae for the closed loop gains are incorrect and this sets a limit on how large those resistances can be. In any case, even if $V_{in} = 0$ in the circuit of Fig. 12, the voltage at E will not be zero because of input bias current, and so V_o will not be zero. For example, if $A_{CL} = 10$ and $R_1 = 100\ k\Omega$, then a bias current of 100 nA would result in $V_o \approx 0.1V$. This is reduced if $R_1 = 10\ k\Omega$ to $V_o \approx 0.01V$. In addition, since V_o is a function of the voltage <u>difference</u> at the op. amp. inputs, inserting a suitable resistance R_2 (Fig. 12) can further minimise the effect. The best value for R_2 is $R_1R_f/(R_1 + R_f)$. Any remaining effect can be balanced by the null potentiometer.

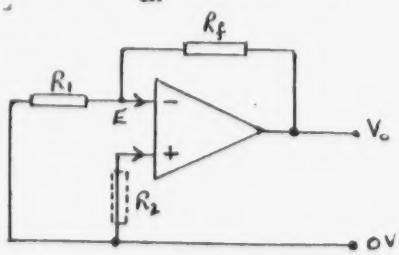


Fig. 12

In some circumstances, it may be necessary to change R_1 during operation or it may be necessary to tie the +input to OV. Then, the input bias current for the -input can be supplied as in Fig. 13. To adjust such a circuit, the op. amp. inputs are linked (---) and the null potentiometer adjusted to the point where V_o suddenly changes sign. The --- link is then removed, the circuit input is connected to OV, and the current offset potentiometer adjusted to give zero output. Removing the input connection should then not have any effect on V_o.

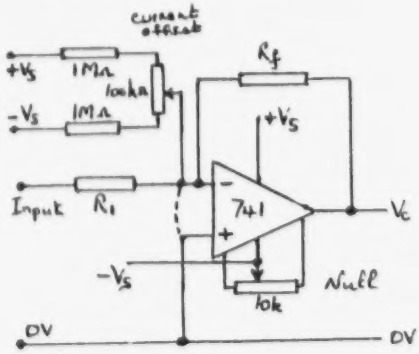


Fig. 13

In the case of the integrator (D), input bias current causes the integrator to integrate any off-set voltage so that the output drifts and eventually saturates. A current biassing circuit (as in Fig. 13) can be used to minimise the effect. The feedback capacitor must first be discharged and then the current off-set potentiometer adjusted to give minimum drift of the output voltage V_o.

Unfortunately, bias currents are functions of temperature and frequent checks of drift are necessary, especially if the input resistance is large. Op. amps. with FET inputs are now available (081) with bias current of the order 10pA and input off-set current 1pA. They have obvious advantages in this respect.

5. Slew-Rate

A further limitation lies in the rate at which the output voltage can change when the input changes suddenly. This is called the Slew rate and is typically about 1V/μs. It is not a limitation which need be considered unless there is a requirement for large output voltage swings at high frequency. Then a high slew-rate op. amp. must be chosen.

USING THE OP. AMP. AS A COMPARATOR OR SWITCH

In these applications, the op. amp. is used in its saturated states, being switched between these states by voltages applied to the inputs. Note that, in these circumstances, the voltages at the + and - inputs are NOT necessarily virtually the same.

(a) Switch Sensitive to External Physical Conditions

A suitable transducer (e.g. a photo resistor) is required (Fig. 14). Variable resistance, R, determines the level at which the op. amp. output switches from positive to negative saturation, which occurs when the transducer's resistance equals R. Obviously, the op. amp. could be used as a bridge-balance detector by connecting the +input to the junction of another pair of resistors in series across the power supply (Fig. 15). However, a word of warning is necessary - the circuit will suffer from common mode errors if the voltages at the inputs depart appreciably from zero, and the op. amp. output is not saturated.

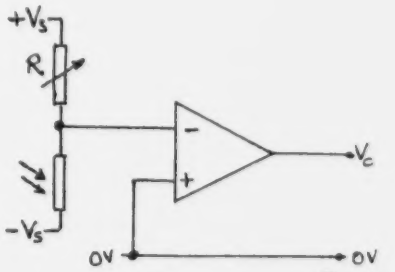


Fig. 14

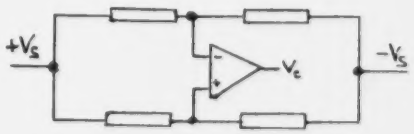


Fig. 15

(b) Switch with Hysteresis - the Schmitt Trigger

In the circuit of Fig. 16, switching occurs when V_{in} reaches the value $+{}^{R1}/_{R}\, V_{sat}$. Positive feedback ensures a very rapid switching action because the output changes to $-V_{sat}$ so causing the potential of the +input to fall. The circuit switches back to its original state when V_i shows a 'hysteresis' effect whose magnitude is controlled by the setting of the potentiometer. The circuit is usually used when a square wave is required from a sine wave input of highish frequency.

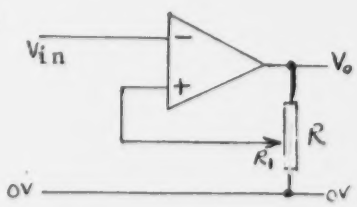
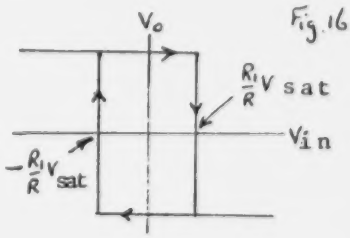


Fig. 16



(c) Positive Feedback - the Astable Circuit (Square Wave Generator)

The circuit of Fig. 17 employs positive feedback and the hysteresis effect to generate a continuous train of square waves. Suppose V_o is at positive saturation (+10V) and that the voltage at P is +2V. Capacitor C is charging exponentially towards +10V through R_f. When

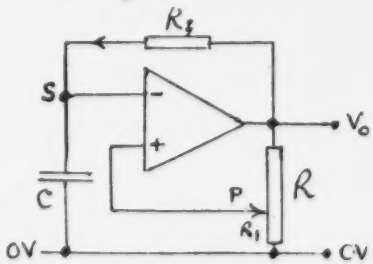


Fig. 17

the potential at S reaches +2V, V_o becomes -10V and V_p becomes -2V. Current now flows through R_f to discharge C and then charge it in the opposite sense towards -10V. When the potential at S reaches -2V, the op. amp switches again and the process repeats. Thus a symmetrical square wave between +10V and -10V appears at the output, the frequency being controlled by R, R_f and C.

In Fig. 18, graph (a) shows how the voltage across C(V_c) varies with time, whilst graph (b) shows the variations of the output voltage (V_o) and the voltage at P(V_p). The frequency $f = \frac{1}{2T}$ and T may be shown to be equal to $CR_f \log_e\left(\frac{1+\beta}{1-\beta}\right)$ where $\beta = {}^{R_1}/_{R}$.

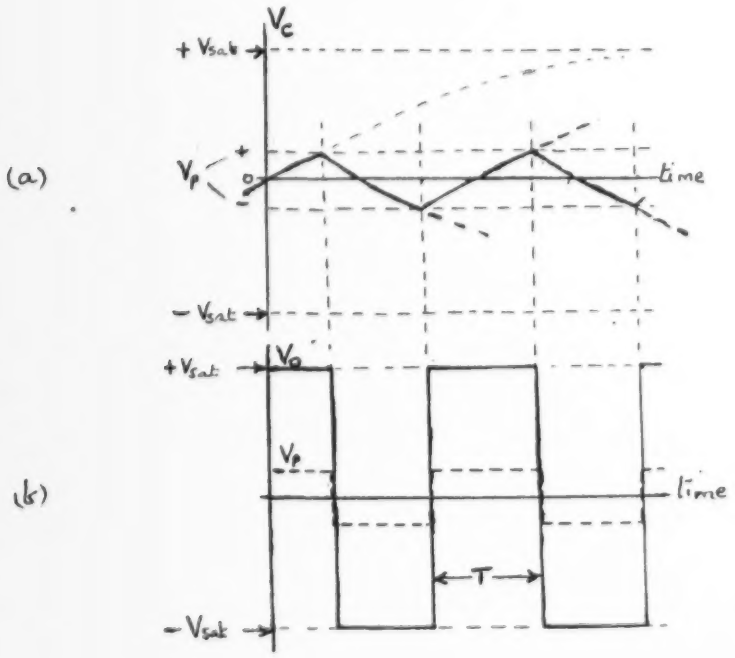


Fig. 18

The frequency of oscillation, assuming the amplifier's positive and negative saturation voltages have the same magnitude, is given by:-

$$f = \frac{1}{2CR_f \log_e\left(\frac{1+\beta}{1-\beta}\right)}$$

If β is small, then $\log_e\left(\frac{1+\beta}{1-\beta}\right) \approx 2\beta$ so that $f \approx \frac{R}{4CR_fR_1}$.

CONCLUSION

To conclude this brief introduction, though the op. amp. type 741, is undoubtedly a good general purpose amplifier, op. amp. type 081 is even better. The input bias current is less by a factor of about $x10^{-4}$ so that the input bias current and input offset current arrangements mentioned above, (4), are not necessary. And at the time of writing and in the UK, it is cheaper than a 741.

A TIDAL SIMULATOR FOR THE STUDY OF SMALL MARINE ANIMALS

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The purpose of this paper is to describe the proceedure for the construction of a tidal simulator which can be so adjusted so as to simulate the natural conditions prevailing within a preselected marine habitat.

The behavior of small marine animals in their natural habitat is often a difficult subject to study.The exceptions are so few as to be of no consequence.Plankton and macro Plankton move at the whim of the current and their study requires little more than a large tank which is aerated and gently stirred.The response of these creatures to abnormal polutants particularly those introduced by man is easily observable.This simplistic approach has serious limitations as the studies move upward through the food chain to the extremely large planktons,larve,small shrimp,krill and the very small fishes.Some but by no means all of these animals still exhibit a largly plantonic pattern,while others show clear evidence of independent directional movement when subjected to tidal currents.Between these two extremes there exists several families of small animals which display a variable response pattern to tidale flows. Depending on the rate of flow of the water these animals may behave as plankton or as independent swimming individuals.it was the need to study the effects of polutants on this switch on switch off behavior that caused this piece of equipment to be constructed.Clearly such observations can not be carried out in a tank because most of the stimulating factors are absent or spurious.The original study was

to assess the response of these multi-behaviorals to any unnatural conditions in order to detect any significant changes in their interaction within the food chain.

Tidal simulators are at the disposal of investigators in several Institutions through the world.However, the installation is very expensive and must be considered a luxury beyond the means of most less fortunate Institutions located within the developing countries.Ingenuity, common sense,and a degree of unorthodox thinking can sometimes produce a solution to seemingly insuperable problems. First and foremost determine the basic needs then hunt around and see what materials can be adapted or used as a basis for adaptation in order to construct the desired item of equipment.Provided it works it does not matter what it looks like.

The functional requirments of a tidal simulator are fairly straight forward.It is a device which will contain water and be of sufficient length to allow time for the directional flow to influence any marine inhabitants contained therein.The capability must exist for changing the direction of flow and the strength of that flow in a sequence which imitates the conditions prevailing within the natural enviornment wherein the species selected for study are normally encountered.

A study chamber of maximum feasible length made of transparent material is supported in a V-shaped trough and is fitted with inlet,and outlet tubes which in turn are coupled to control valves,timing mechanisms,tanks,and pumps.Large bore glass tubing is ideal because it is available in standard lengths and only needs to have any sharp edges smoothed over with emery cloth before being installed.The tubes are joined together using sections

of automobile innertube which are cut so as to make bands fifty millimeters wide and the size of the tube is chosen to allow the band to stretch reasonably when it is in place on the tube.The seal is leak proof and allows for some flexibility between the assembled pipes.The study chamber is closed at both extremities by end caps which incorporate short tubulations which allow for the flow of water,and access to the study chamber itself.Within the end caps a cluster of small tubes which have been lightly cemented together is retained in position using brass or stainless steelring clips.Glass tubes three millimeter in diameter are ideal but this dimension is not critical.Plastic drinking straws are an acceptable subsitute.The cement should epoxy or one of the plastic types the criteria being insolubility and be non-toxic.The entire unit is supported on a V shaped trough and is equiped with accessories which regulate the flow of water through the system.The schematic layout is shown if Fig.I.

Details of the end caps are illustrated in Fig.2.It should be noted that only one of these units is fitted with a drain cock.Extension tubes are attached to the stubs on the end cap and are high enough to allow for a small amount of pressure in the system in order to simulate the shallow water or near surface habitat of the animals being studied. The pairs of tubes at the extremities have side arms attached and it is through these side arms that the water flows in and out of the study chamber.It should be noted that in both pairs the outlet side arms are higher than the inlets this difference in levels represents the pressure in the system.The tubes adjacent to the study are of larger diameter and serve two purposes,they allow for the introduction of the animals and for the introduction and removal of a

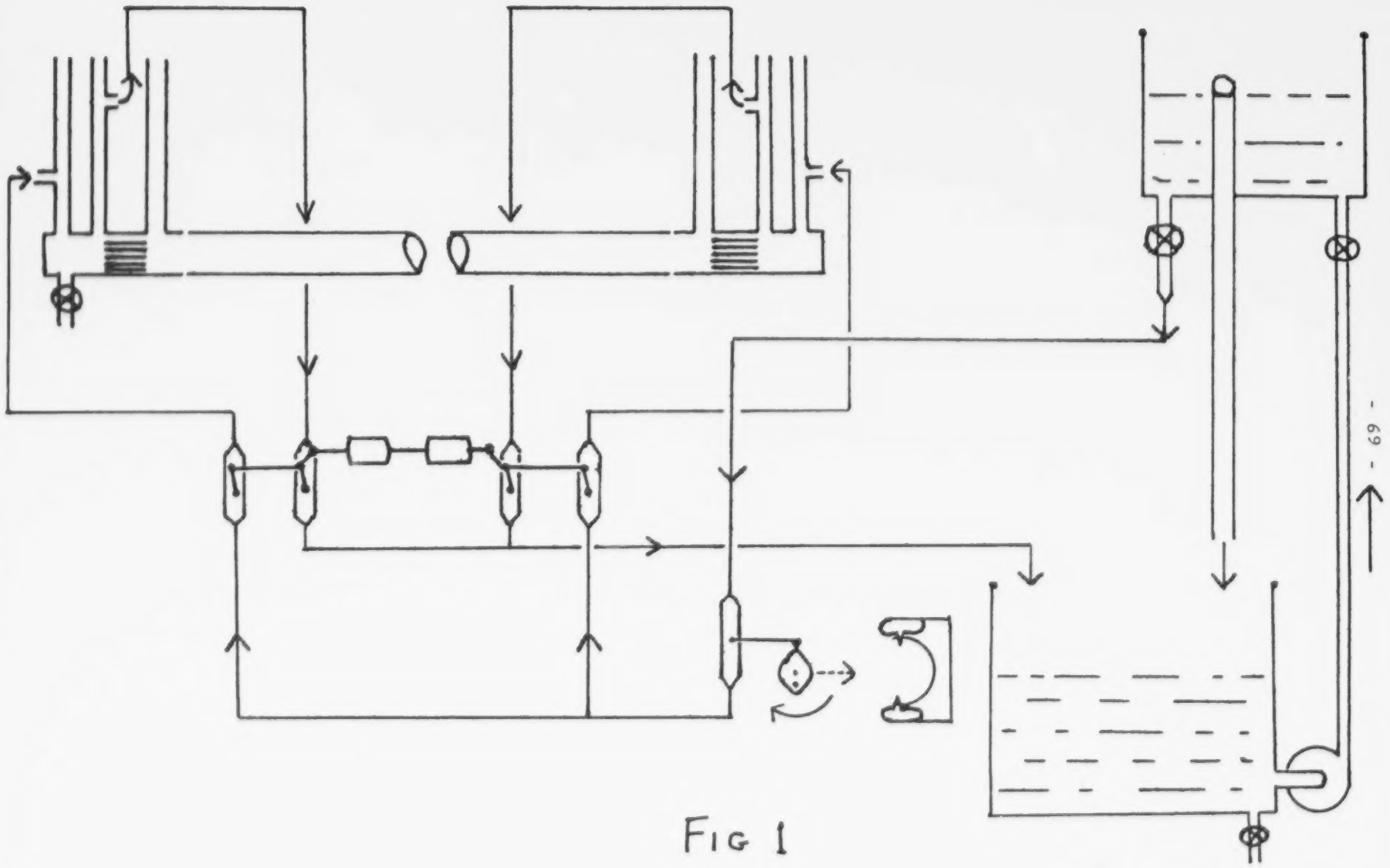

FIG 1

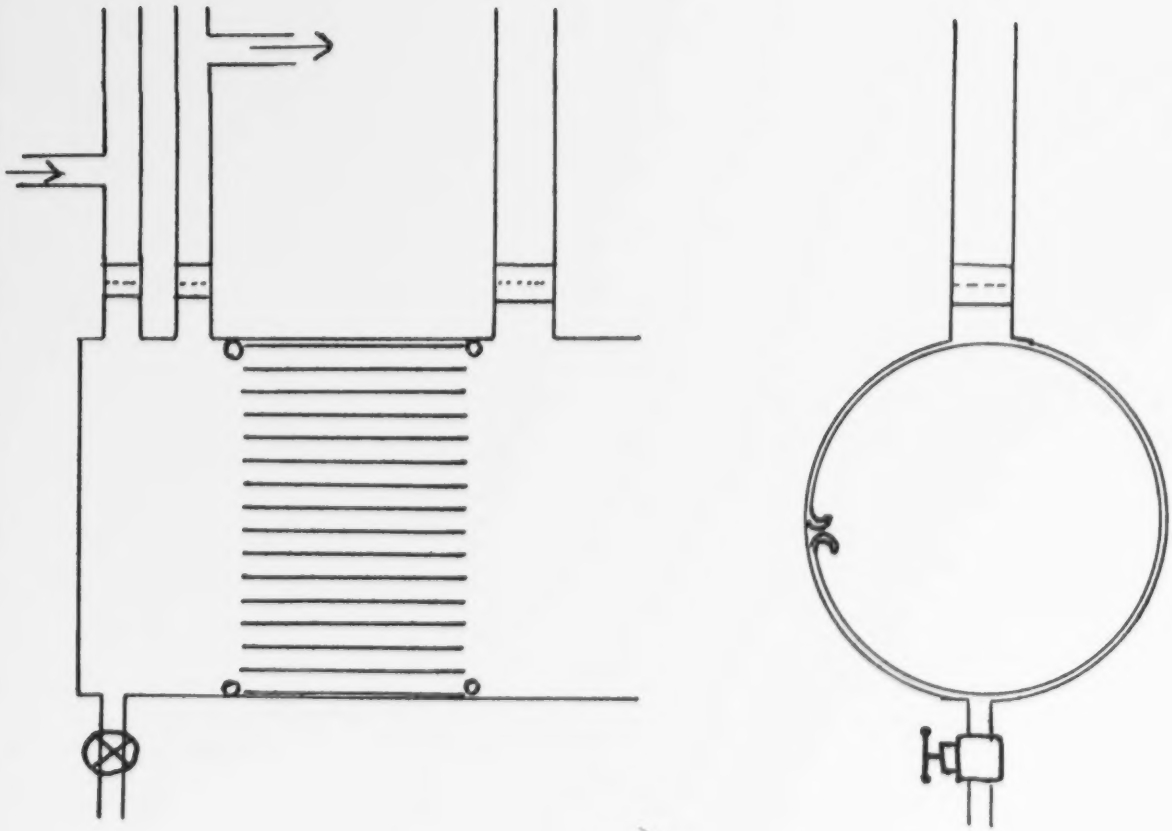

FIG 2

calibrating device.The study chamber itself is enclosed by the clusters of tubes which serve to smooth out turbulence effects caused by the inward flow of water,at the same time the clusters form a barrier to prevent the animals from being swept through the system.When the animals are smaller than the cluster orifices a piece of fine mesh is placed over the end ofthe clusters.

The direction of flow is reversible within the study chamber and is controlled by two pairs of valves which are operated by solonoids powered by an automotive battery.The unit is illustrated in Fig.3a.The valves are home-made and are based on the butterfly vane used in carburettors.Commercial valves are unsuitable because of the complicated mechanisms needed to operate them simultaneously.The operating principle is shown schematically in Fig.3a.Transverse movement of the rod coupling the two sets of linkage arms causes the vanes in the valves to move so that in each pair one valve is open and the other is closed.Refering once again to the schematic it should be noted that when the left hand inlet valve is open the left hand outlet valve is closed, and the inlet valve of the right hand pair is closed while the outlet valve is open.Thus water will flow from left to right through the study chamber.When the coupling rod moves to the right the direction of flow is reversed and simulates the natural ebb and flood of tidal waters.It has been found that the solonoids used on automotive starters are easily modified to provide the motive force to operate this unit,the power is in fact more than is desirable and must be moderated by a rheostat otherwise there will be serious damage done to the vanes within the valves.The rod itself consists of a

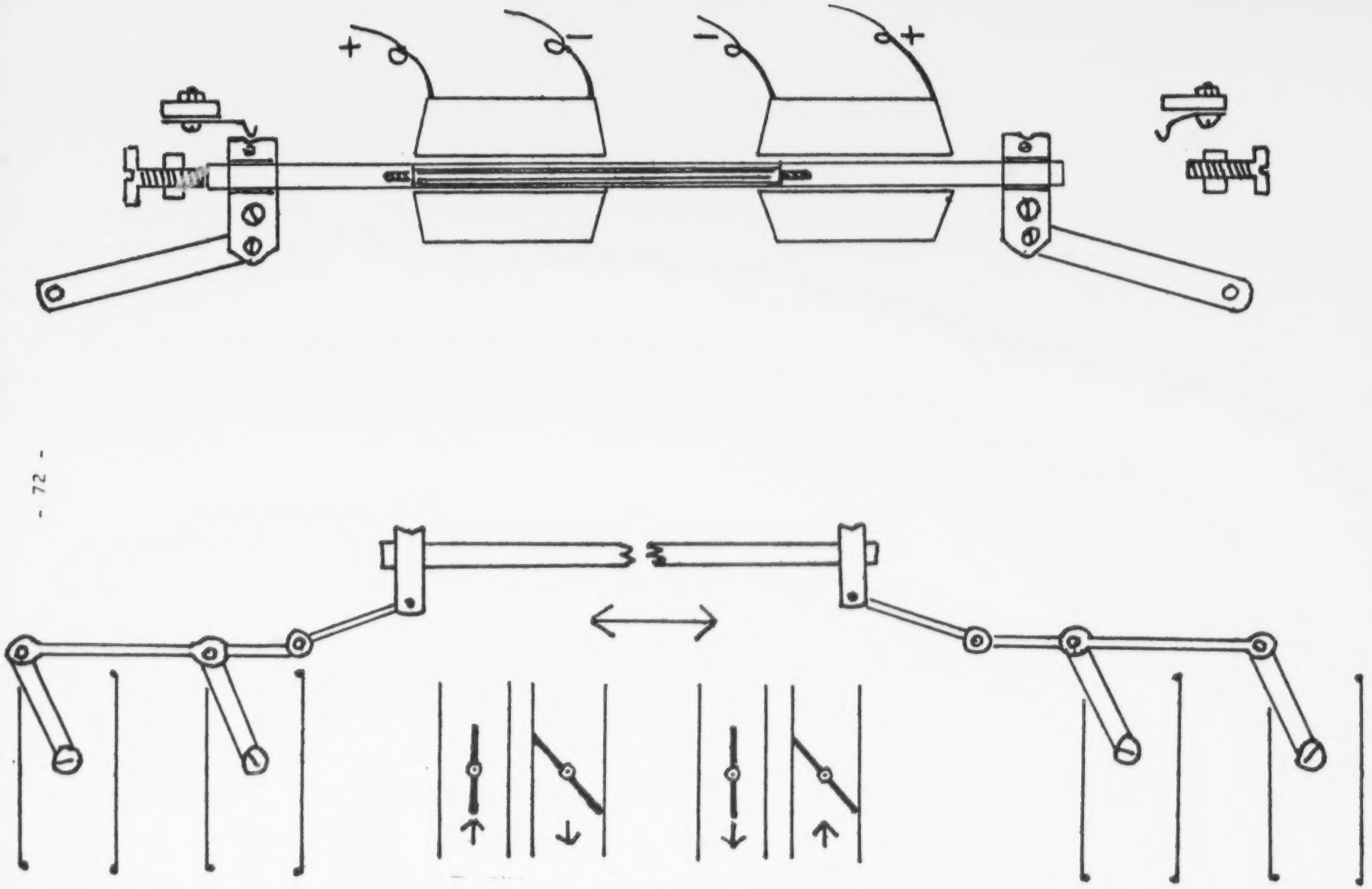

FIG. 3a

center section of steel while the two outer pieces are of non-magnetic material,either brass or any suitable plastic material.Magnetic attraction from either of the solenoids causes the rod to move across to the activated one the total extent of this movement being limited by the stop screws at each end of the assembly. The linkage arms are attached to the ends of the rod by means of sheet metal straps which are firmly attached to it using screws supplemented by some adhesive,solder or epoxy it is essential that this clip is rigidly mounted.A hole on one side serves as an attachment point for the linkage arms while on the other side the clip is notched to accommodate a light spring which serves to hold the rod up against the limiting travel screw.Both the limiting screw and the spring are adjustable and are set in such a way that those valves at both ends of the unit which are in the closed position are not subjected to excessive force.The seating of the rod is automatically accomplished because the solonoid remains activated for several seconds while the cam in the timing device triggers a micro switch. The linkage arms are made of stiff wire or strips of metal.In the case of wire hooks and eyes are made with pliers while the strips are drilled and subsiquently linked together with screws and nuts.The movement should be free but without any excessive play.

The valves which are illustrated in Fig.3b are made of brass or plastic which ever material is available .A tube the bore of which is larger than that which is needed to supply water to the system at its maximum capacity has two solid stubs attached to it using solder or cement,one of the stubs being longer than the other.They are attached opposite to

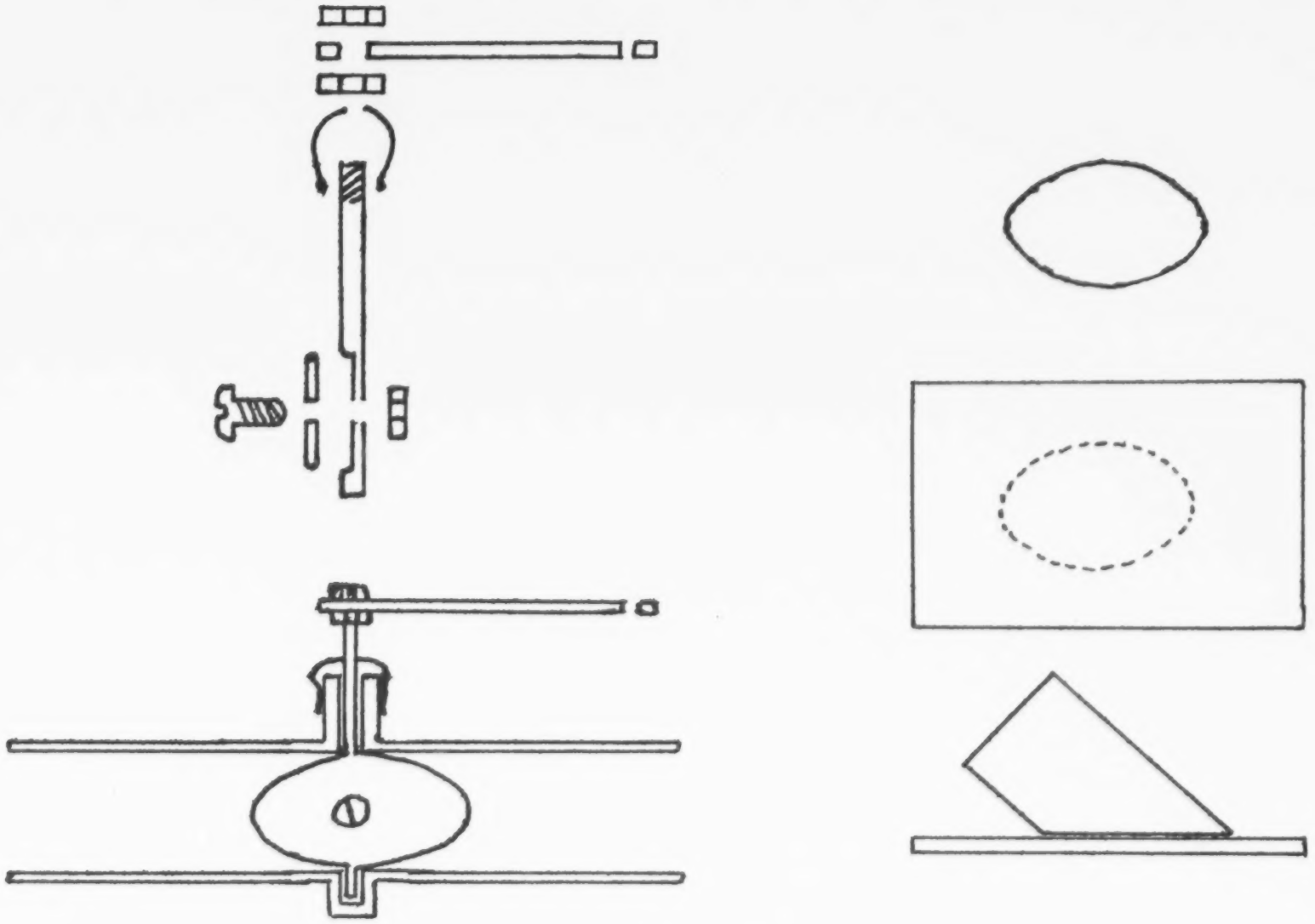

FIG 36

one another.The length of the valve body is ten centimeters in order to have easy access to the vane.A piece of round rod five or six millimeters in diameter is selected brass being the best material,its exact diameter is measured and a metal drill of the same size is used to drill a hole which passes through the longer of the two stubs and enters the other one to a depth of five millimeters.When the rod is inserted through the top stud it should locate into the seat in the other stud and should turn easily without excessive free play.While the rod is seated a metal scribe is used to mark where the rod coincides with the inner wall of the tube it is then removed and the material is filed away to form a flat seat which is half way through the rod and which extends one millimeter beyond the marks which correspond to the diameter of the tube,this is to ensure that the vane will sit flat against the rod.The vane is cut out of a sheet of soft metal ,copper or aluminium,are suitable or plastic may be used.The vane is oval and sits at an angle within the body of the valve this design permitting the valve to open and close with only a small turnig circle.
A template is made by sawing through a piece of tubing which is identical to the valve body,the cut being made at an angle of forty five degrees.After smoothing the cut surface the template is pressed down onto the sheet of material and a mark is incribed around the inner contour of the template after which excess material is cut away.Final sizing is done carefully using a file,and finishing off with fine emery paper. The edges should be rounded. With care ,and attention to good workmanship it is possible to adjust the vane so that in closed position it seats well against the walls of the tube.A central hole is drilled through the vane and it is inserted into the valve body and then adjusted so that it seats down

into the flat seat of the rod the vane and rod are moved about until the hole in the vane is opposite middle of the rod and a mark is made by passing a pointed needle through the hole in vane and scoring the rod.The rod is drilled through using the same size drill as the one used for the vane and the two pieces are joined together with a small screw and nut,preferably made of brass.The small clearance where the rod emerges through the stub is sealed against leakage by a rubber cap which is easily made fron a feeding teat or a pen filler.An arm is attached to the end of the rod by threading it with a die and using two nuts one below and one on top,the final tightening being done after all the valves are assembled and their linkages attached to the traversing rod making sure at the same time that the vanes are all positioned correctly, the necessary adjustments have been made to the travel limiting screws and the locking springs.A word of warning is needed do not attempt to test the unit using the solonoids unless the assembly is filled with water which slows down the rate of turn of the vanes.The valves are connected to the appropriate tubes on the end caps as illustrated in Fig.1.

In order to simulate the characteristics of tidal flow it is necessary to locate a variable flow device on the supply side of the inlet valves so that maximum and minimum tidal effects which must be synchronized with the change in the direction of flow thus simulating the natural cycle of events. At the same time the entire process must be timed to correspond with the specific natural sequence of sea level oscillations of the location under study.Tides rise and fall in a period of approximately twenty-four hours fifty minutes so that the cycle advances just under an hour in each full day. Tide Tables are available which give the time of high tide at Standard Ports and if the location is close to one of these

places the data can be used to run the unit in sequence with the natural rhythm of the tide.In areas far removed from the Standard Ports it will be necessary to make observations on the spot.Two items of information are needed in order to program the unit so that it will behave in a natural sequence.

The equipment needed to determine local tidal conditions is simple to makeand is illustrated in Fig.4.Current velocity is determined by timing the delay between putting a floating device into the water and its arrival at a point some distance away. If that distance is known the variations in velocity from slack water to full flood can easily be calculated.Refering to Fig.4.the left hand boat is firmly anchored while the right hand boat moored by means of a light chain or pre-stretched rope of known length.The actual distance between will be governed by the location but should be as far as possible.The lead boat is anchored in position shortly before high or low water this information having been previously obtained.When slack water is observed the time is noted,then as the current starts to flow the mooring line to the second boat is paid until it is positioned astern of its neighbour.The operator in the lead boat places a simple floating indicator into the water at the stern of the boat and indicates the action to the operator in the second boat who times the delay between the float entering the water and the moment that it reaches the bow of the second boat,this proceedure is repeated several times until slack water is again evident.Of course these observations must be carried out in calm weather,a windy day is useless. The floats are made using a cork which is sandpapered into a

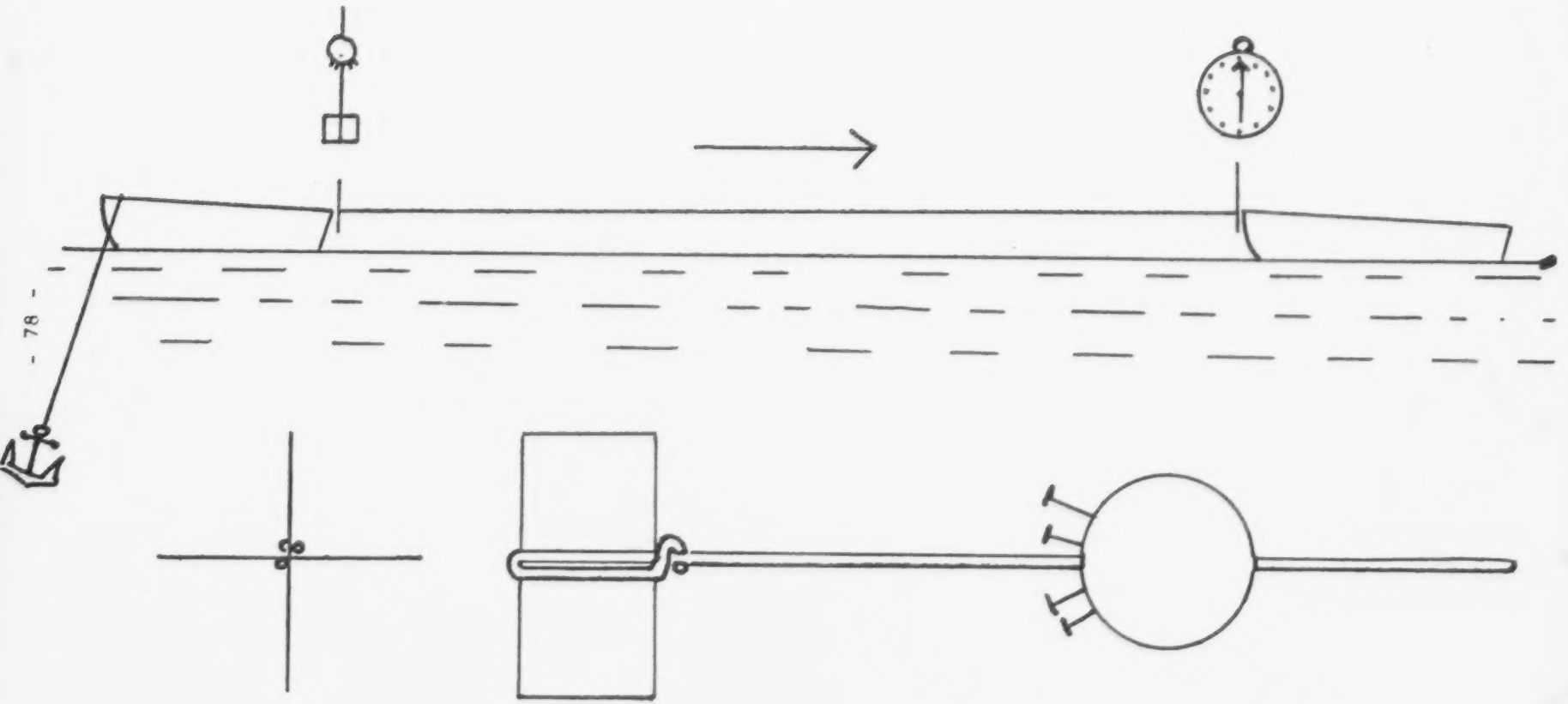

FIG 4

rough ball.A keel is made by folding a strip of aluminium foil to make a four armed shape which is ten centimeters wide, and five centimeters deep. This is attached to a piece of stout copper wire one end of which is bent into a hairpin and attached to the keel.The other end of the wire is then pushed through the cork so that it projects through the other side.The total length of the float is thirty centimeters with five centimeters projecting beyond the cork.Both the cork and wire are painted fluorescent red to improve visibility.The floats have to be calibrated by adjusting their buoyancy so that they only just float exposing the minimum amount of surface above the water,this is to minimise wind effects.In order to achieve the desired amount of buoyancy the floats are placed into a tank containing water which has been taken from the location being studied.Variations in salinity,particularly in coastal waters will have adverse effects on the calibration,however,fresh water is fairly constant.The final adjustment is made by pushing small nails into the underside of the cork until the device only just floats.Any small errors can be corrected at the test site

A timing mechanism is needed which will operate a variable flow valve and at the same time cause the necessary changes in the direction of flow.Achieving these requirments is quite a simple matter.The ideal timer is made from a large alarm clock which is spring wound,synchronous electric ones are not suitable because they can not be re-timed.The mechanical clock is equipped with an adjuster at the back which makes it a simple matter to set the clock to run fifty minutes slow in each twenty-four hour period,the slot in the regulating device may have to be lengthened in order to extend its range. The hands are removed and a short metal extension is fitted to the hour hand,this should incorporate a set screw which

locks the extension firmly on to the stub,and be threaded at its other end to accept a screw.A cam is made from metal or plastic which is roughly oval in shape but sharply pointed at the ends of its major axis.The actual contour of the cam is based on the tidal data relating to the site slack water, corresponding to the peaks of the cam,The distance from the centre decreasing as flow velocity increases. During the period of full flood and ebb the contour of the cam is circular.A modified vane valve is mounted so that the valve turning arm rests on the top edge of the cam and is about twenty-five degrees above horizontal.The arm is kept in constant contact with the cam by a light spring which is located between the arm and a hook attached to the body of the valve,this spring should only be strong enough to keep the valve closed against the pressure of water from the cistern which supplies the water to the system see Fig.1.It is important to ensure that when the valve arm is at the highest point on the cam the vane is in the closed position and that it is correctly orientated.Logically the valve will open and close in sequence with the rotation of the cam.A mechanism which consists of two micro switches mounted on a supporting bracket is firmly fixed to the same base as the one holding the clock.The mounting tags of these switches are sloted to allow for some adjustment.The switches are activated by a small steel peg which is mounted on one peak of the cam so that it is at a right angle to the cam,a small section of darning needle is ideal.The entire assembly is illustrated in Fig.5.which also shows the wiring sequence for connecting the micro switches to the directional control solonoids.It is evident that rotation of the cam will cause the direction of flow to change four times during a full day.

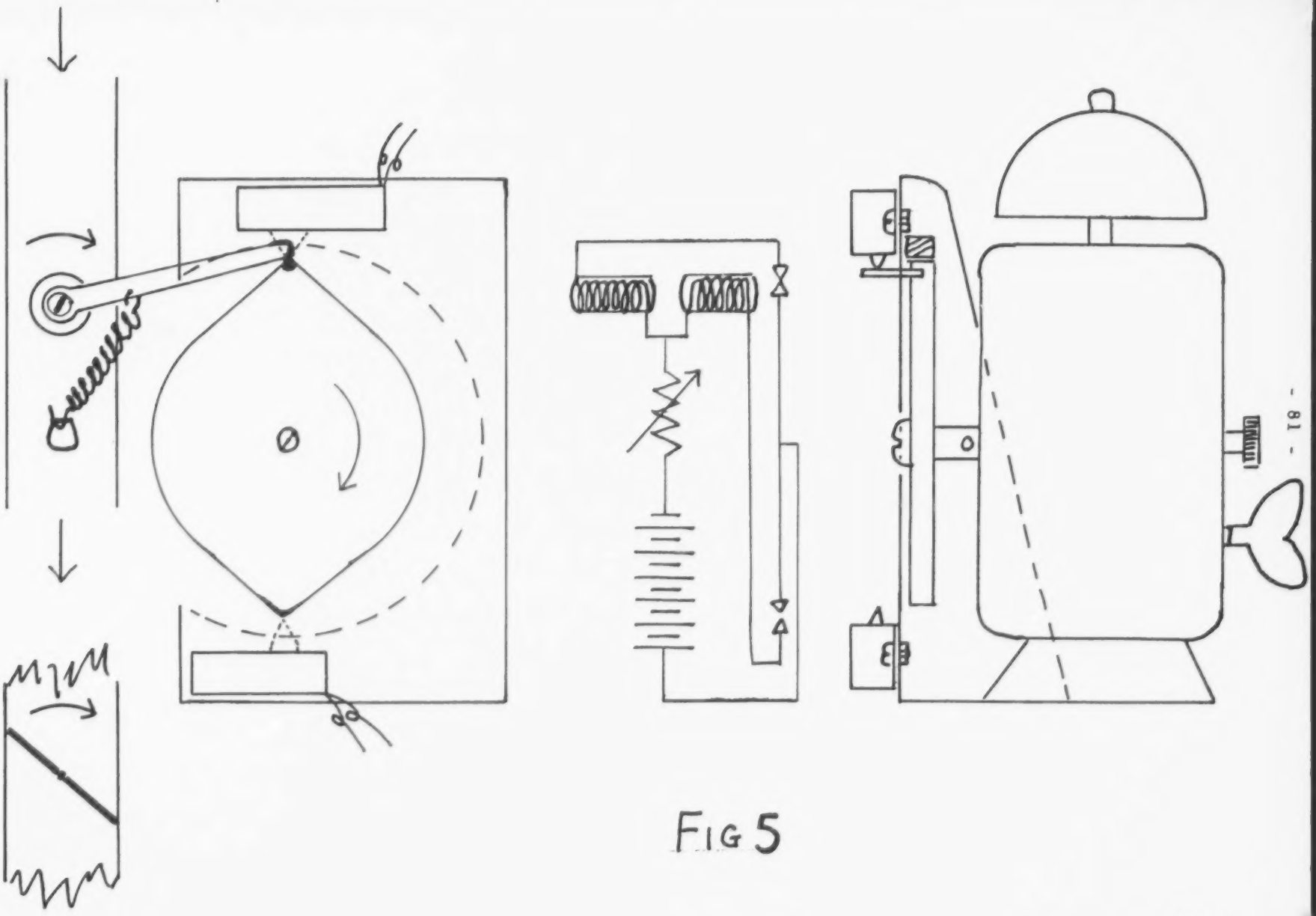

FIG 5

There remains one control to be incorporated into the system namely maximum flow velocity.It has already been emphasised that the vane valves should be large enough to exceed the maximum flow through the system this is in order that a limiting valve can work effectively.This valve is a commercial gate model which is operated by turing a handle several times. It incorporates a gland nut which can be tightened down so that it becomes difficult to alter the setting of the valve accidently. Referring to the information obtained from the site, it now remains to calculate the amount of time need for water to pass from one side of the study to the other.Once again a simple cork which has been weighted down with steel nails is used to supply the necessary information . This time however, the cork is adjusted so that it is suspended in the water rather than just floating. This adjustment is a little bit difficult as some corks will not be suitable,it is a matter of trial and error.To set the maximum flow the gate valve is opened fully, and water is allowed to flow through the system. The indicators are dropped into the study chamber at one end and their passage is timed to the other end. The gate valve is closed step by step until the transport time of the indicators corresponds to maximum velocity of the tide.Finally the gate valve gland is tightened down,and the indicator balls removed with a magnet.

Refering once again to Fig.1, water is supplied to the system from a cistern which is mounted above the outlets of the end caps,the actual height to be such that while there is sufficient pressure exerted to supply the maximum demand of the system it should not be allowed to exert excessive pressure against the valves.The cistern is kept constantly supplied with water contained in the holding tank via a pump,and it returns through an overflow pipe which does not dip beneath the surface of the water the resulting splashing helps to aerate the water.The overflow acts as a constant head thus

preventing pressure surges within the system.The pump is mounted low down so that it is self-priming and is selected so that its capacity is significantly greater than the demand of the system. A gate valve is installed between the pump and the cistern to provide control.The actual sizes of the tanks will depend on the volume of the study chamber,but it is important to bear in mind that the holding tank should have a capacity at least fifty times that of the study chamber,the cistern being about half as large.The holding tank is equipped with a drain cock to permit changing the water as required from time to time;the cistern empties through the pump.Note that the study chamber remains full during this operation;however,this is essential for the survival of the inhabitants.When it becomes necessary to clean out the entire system the chamber is drained through the cock in the left hand end cap;then the extension tube of the left hand stub giving direct access to the chamber is removed,being replaced by an inverted U-tube which leads to a drain.The drain cock is closed and a generous amount of water is introduced through the right hand access tube which remains in place;the flow sweeps the animals out of the system. The entire study chamber with its end caps is mounted so that the left hand end is slightly lower than the right hand end in order to facilitate the draining procedure.

The simulator as described herein was made out of glass tubing using locally available glassblowing services.Unfortunately this type of service is not available to many of those who need it. An alternative method of fabrication must be sought. Metal tubing and sheet can be shaped and soldered,and plastic material offers some interesting possibilities.The only real problem is the study chamber which of course must be transparent in order to function.This problem is overcome by using double thickness window glass,this material is available everywhere,and

can usually be purchased as sheets three feet by two feet.In order to make the sections of tube the glass sheet is cut into strips two feet long (three foot sections are difficult to handle) and of such a width so as to form a square sectioned tube of the desired size.However,when selecting the size of of the tube it is necessary to bear in mind that the pieces are cemented together with silicone rubber cement which makes a strong joint,but never-the-less the pipe is not as strong as a round glass tube.The rubber bands used to join the sections together can be stretched out over the round so that a very tight leak proof joint is easily achieved but the square tube will collapse if subjected to much force. A compromise is found by selecting an innertube which maybe stretched moderately and the size of the tube is adjusted accordingly. This approach is necessary because the innertubes are only available in a limited number of sizes.A simple wooden support is made to hold the sheets in place while the cement hardens.The edges of these tubes are very sharp and this problem must be rectified by rubbing the edges with emery paper;otherwise the rubber rings will be cut,and the assemblers will suffer several cut fingers. Because of the light pressure which can be exerted by the rubber rings it will be necessary to smear a little cement on the glass so that the rubber will seal the joint properly.Of course the end caps are fabricated so as to fit the square section,copper sheet is an ideal material to use.

It remains only to offer a few words of advice to the assemblers.A V-shaped trough is made out of wood and is firmly supported on several feet along its length,the left hand side is fifteen centimeters lower than the right to facilitate

drainage of the study chamber.The trough must extend to the full length of the assembly with only the drain cock projecting beyond the end.Because of the great length of the unit which may go ten or more meters it is impossible to make the trough out of a single piece of wood.Consequently it will not be a precision instrument,the irregularities could cause some stress in the unit.To overcome the difficulty the unit sits on a bed of sand,and it is appropriate to mention at this time that in the event that a square sectioned tube is used it must be mounted on one edge like a diamond otherwise some problems will be encountered;for example it would be difficult to support and would tend to trap wide air bubbles making observation difficult.Of course the end caps must follow the same orientation.

Starting at the left hand side the end cap with the drain cock is attached to the first section and placed down on a bed of sand which is not as long as the section then the next one is laid on another bed of sand so that ends to be joined with are clear of the sand. This procedure will prevent sand from getting into the joint causing it to leak.The remaining sections are joined one after another using the same procedure.When everything has been bedded down the gaps in the sand bed are filled in.

It remains only to express my thanks to Dr Tamas Hamor, formerly of the School of Biological Sciences of the University of Port Harcourt for asking me to devise this piece of equipment,and to thank Professor Thulstrup of the Royal Danish School of Educational Studies for inviting me to participate in this workshop.

TESTING LOW COST EQUIPMENT FOR CHEMISTRY

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Introduction :

In the autumn 1981 Pr. M. CHASTRETTE called me for assistance in an evaluation of a low cost equipment. Dr. K.V SANE from the University of DELHI proposed to test a low cost mV-pH meter that he and his group built in India. Pr. M. CHASTRETTE convinced me that our University was able to help colleagues which are working in our field of interest. Then he proposed to Dr. K.V. SANE to sell and send to LYON three mV-pH meters. In spring 1982 I set up the three instruments in a room devoted to student's practical work in chemistry. About 30 first-year university students used the apparatuses and experimented acid-base titrations. Their job consisted in reporting values, drawing curves, and also in a brief analysis of instrument performance through a questionnaire specially prepared for them. Before that I have also personnally tested the mV-pH meter in potentiometric and acid-base titrations.

The general design of the instrument was previously reported in the preceeding workshop, held in April 1981 at MADRAS (India) and does not need further examination.

I - First checking of the instrument -

I.a - Silver chloride precipitation

I checked the apparatus with argentimetric titration for this experiment is easy to do.

10 ml of a 0,05 M NaCl solution were poured in a beaker along with about 50 ml of de-ionised water. A 0,05 M Ag NO_3 solution was placed in a burette. Two electrodes were dipped into the NaCl solution :

- a reference electrode consisting in a commercial calomel electrode. This half-cell gives a constant potential whatever the solution (e_1 = 0,245 Volt at $\simeq$ 20°C).
- a silver electrode consisting in a small silver rod. This half-cell gives a po-

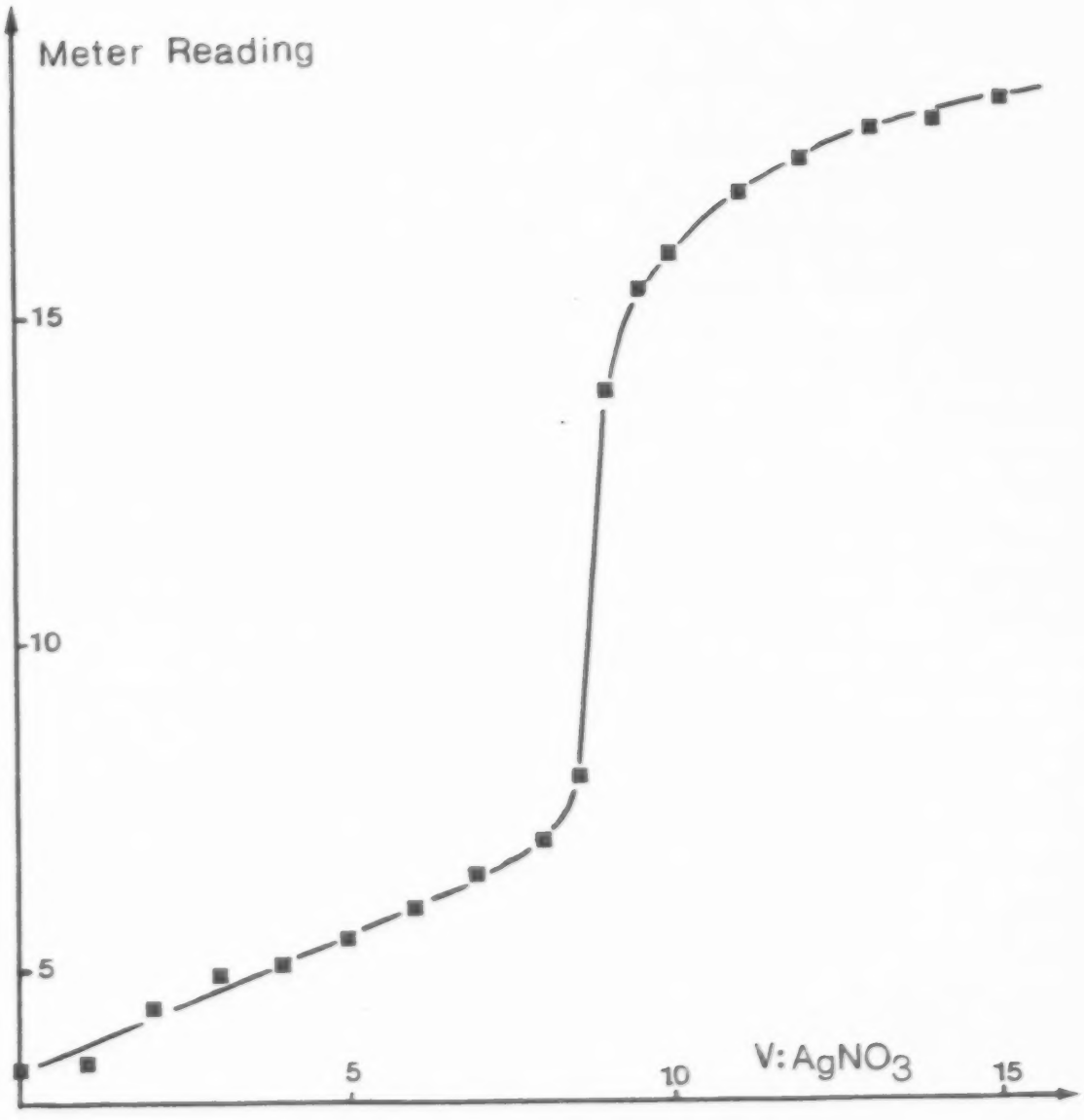

Fig. Ia : Titration of NaCl against $AgNO_3$

tential that varies with $[Ag^+]$ concentration of the solution according to the Nernst equation.

$$e_2 = 0{,}800 \text{ Volt} + 0{,}059 \log [Ag^+]$$

During titration the e.m.f. of the cell was easily read on the meter in accorddance with the chosen scale.

The result of the precipitation is illustrated in Fig. I.a. At the end-point of the precipitation I determined the potential difference between the two electrodes by calculating the theoretical deviation of the meter. Then I calculated Ks (Ag Cl) according to the following procedure.

- deviation of the meter : 11,6 : determined on the graph with the 2V scale.

- e.m.f. of the cell : 11,6 x 0,02 = 0,232 V
- e.m.f. relative to the H^+ / H_2 reference half-cell :

$$0{,}232 + 0{,}245 = 0{,}477 \text{ V}$$

then :

$$0{,}477 = 0{,}800 + 0{,}059 \log [Ag^+]$$

$$\log [Ag^+] = -5{,}48$$

$$[Ag^+] = 10^{-5{,}48} = 3{,}3. \ 10^{-6}$$

$$Ks = [Ag^+] \ [Cl^-] = 1{,}1. \ 10^{-11}$$

The true value is 10^{-10} at 25°C. I think that the obtained value is excellent considering the temperature of the room (18 - 19°C) and the different potentials between wires and connections that were neglected.

I.b - Acid-base titrations

In this experiment I neutralized a 0,1 N HCl solution with a weak base (C_2H_5-NH_2) or a strong one (NaOH).

10 ml of the acidic solution were poured in a beaker with 60 ml of water. The basic solution was placed in a burette. Two electrodes were dipped in the beaker :

- a reference electrodes (calomel electrode e_1 = 0,245 V)
- an antimony electrode (commercially available)

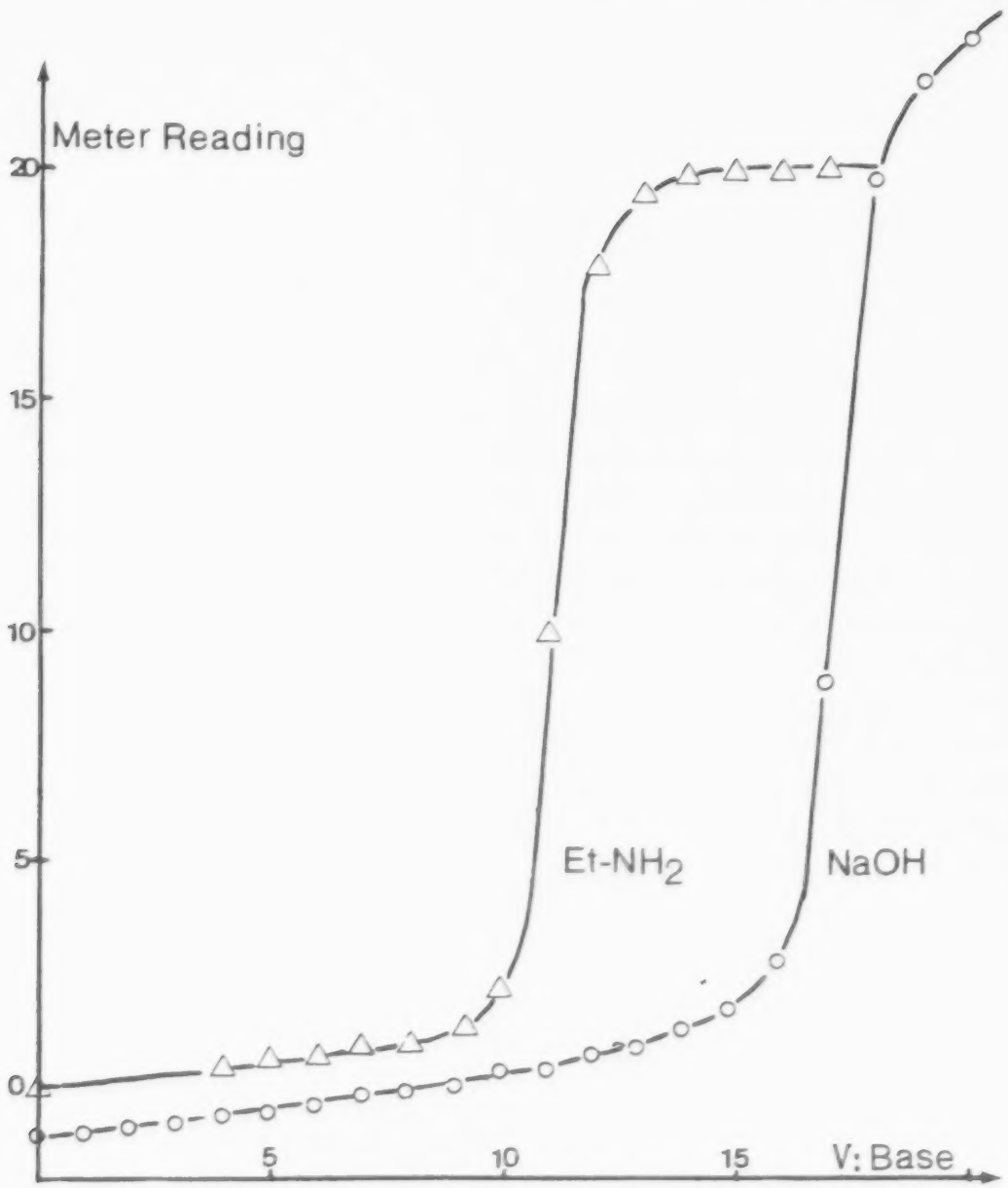

Fig. Ib : Titration of HCl againstethylammine or soda

Its potentials varies with the pH of the solution according to the equation.

$$e_2 = 0{,}150 + 0{,}059\ pH$$

The cell gives then a e.m.f. $e = e_1 - e_2$

$$e = 0{,}245 - 0{,}150 - 0{,}059\ pH = 0{,}095 - 0{,}059\ pH.$$

During the titration the deviation of the meter was reporter and pH was calculated. The results of both titrations are reported in Fig. I.b. One can see that the rapid pH increase at the end of neutralization is very easily observed. Moreover one can determine the pH at exact neutralization by noting the deflection of the meter and by knowing the initial pH. It should be kept in mind that every pH meter has to be standardized before to use : the deviation of the meter, or the pH value that is read, must correspond to exact pH. I used a potassium dihydrogeno phtalate solution (concentration = 0,05 M). The pH of this solution is exactly 4,00 at 20°C. Then the deviation of the meter must correspond to that value. For this solution :

$$e = 0{,}095 - 0{,}059\ pH = 0{,}095 - 0{,}236 = -\ 0{,}141\ V$$

$$\text{deviation with 2 V scale} = \frac{-0{,}141}{0{,}02} = -\ 7 \text{ divisions}$$

In fact, due to bad connections between electrodes and apparatus I obtained $\simeq -10$ divisions. I think that this is of minor importance : it is equivalent to consider having another e_o value for standard potential for antimony electrode. Whatever the initial deflection of the meter, for a given $\triangle$(pH) one obtains always the same $\triangle$(e) and then the same $\triangle$(deflection) for the meter.

The initial HCl solution corresponds to a pH = 1,8 (calculated value). One can determine the deviation of the meter at end-pont of neutralization:

- with the $C_2H_5NH_2$ solution one obtains $\triangle$ = 10,5 divisions that means $\triangle$ e = 0,21 V or $\triangle pH_1$ = 3,5. Then the pH at exact neutralization is then 1,8 + 3,5 = 5,3. From calculus one should obtain pH = 6,4.
- with the NaOH solution one obtains $\triangle$ = 13,5 divisions or $\triangle$ e = 0,270 V ; that corresponds to $\triangle$ pH = 4,6. The pH at neutralization in then 4,5 + 1,8 = 6,3. On should obtain pH = 7 exactly. The discrepancies of these results will be discussed later.

Student's experiments -

The students first received instructions about the job they had to do.

They had to perform acid-base titrations with low cost pH meters. They were explained about the origin of apparatuses, the aims of the work and they were given a sheet containing some instructions concerning the instruments and their use.

Because the instruments gave not pH directly the link between pH and e.m.f. of the cell constructed with calomel and antimony electrodes had to be explained anow (This point was raised in the lectures but somehow did not strike them). They operated three neutralizations :

a) H_2SO_4 / NaOH 0,1 N

b) CH_3COOH/ NaOH 0,1 N

c) NH_4Cl / NaOH 0,1 N

For each experiment they took 10 ml of acidic solution (with pipette) and added 60 ml of water. They placed the basic solution in a burette and two electrodes in solution (calomel and antimony electrodes). They recorded deviations of the meter during NaOH additions.

Before these experiments I explained to them that the pH meter must be standardized with the buffer solution at pH = 4,0. It should be noticed that for same buffer, the deviation of the meter was not the same for the three instruments. Each one gave its own deviation according to the equation :

$$e = a - 0{,}059\ pH$$

For the buffer each student noticed the deviation, calculated e and then determined the "a" factor. They reported the values and calculated the pH in the following form

Instrument I, II or III	"a" factor	V NaOH added cm^3	Deviation of the meter	mV	pH
I	"a"	0	-	-	-
		1	-	-	-
		2	-	-	-
		etc ...	....	....	....

The results were reported in figures they had to drawn. Some are reported in fig. IIa, IIb, IIc. One can see that the general look is fairly good. The students had also to determine the

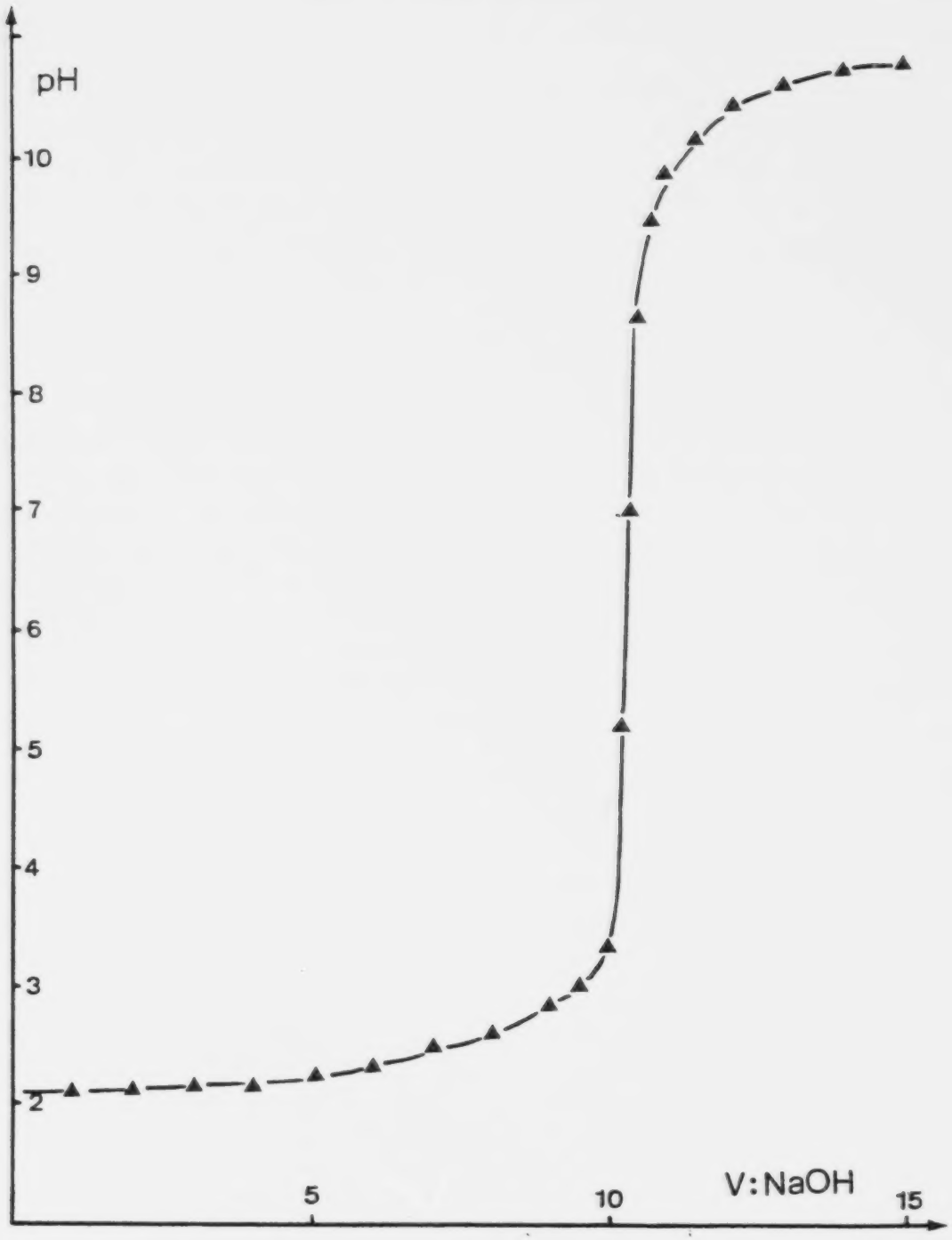

Fig. IIa : Titration of H_2SO_4 againstNaOH

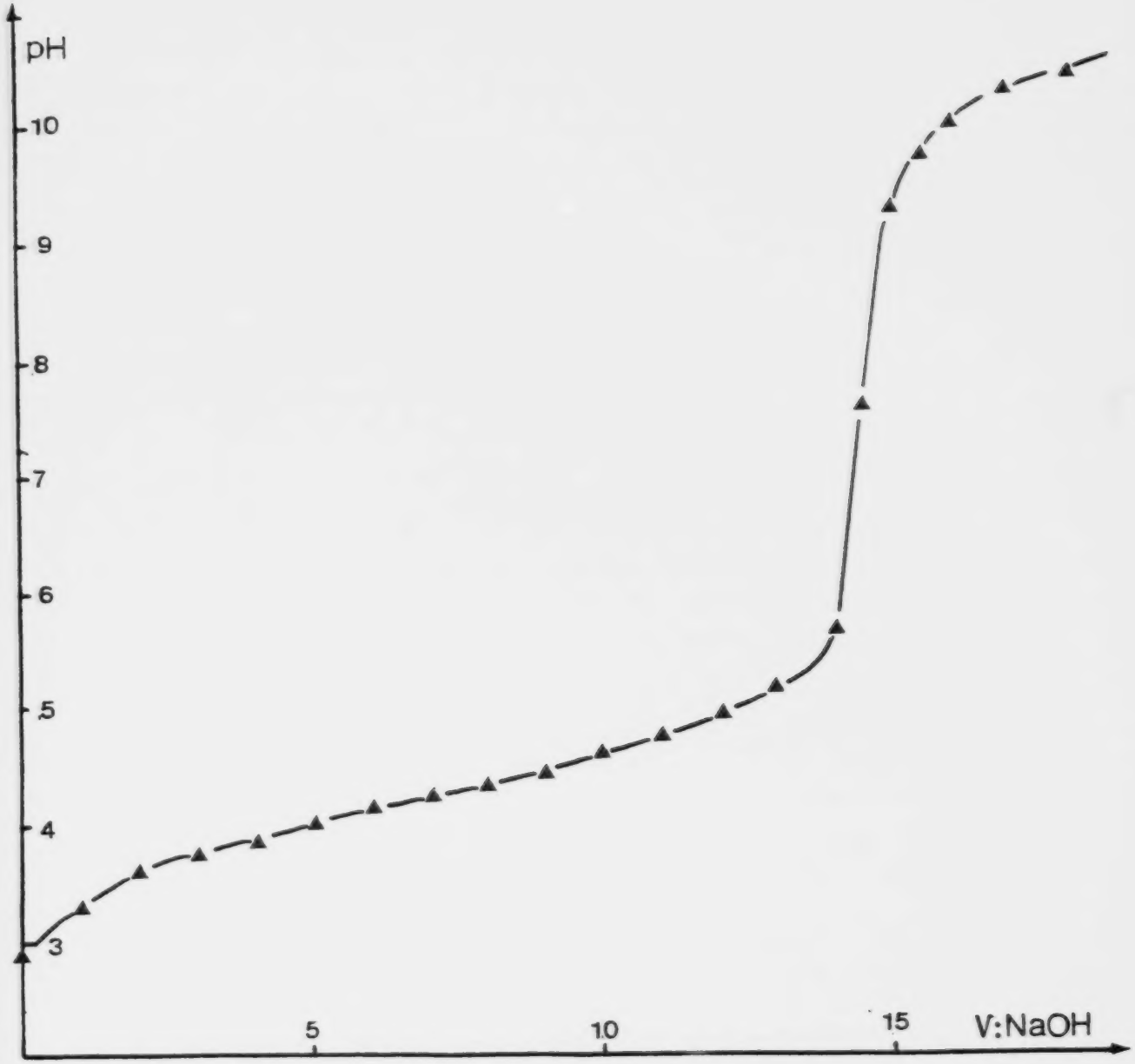

Fig. IIb : Titration of CH_3COOH against NaOH

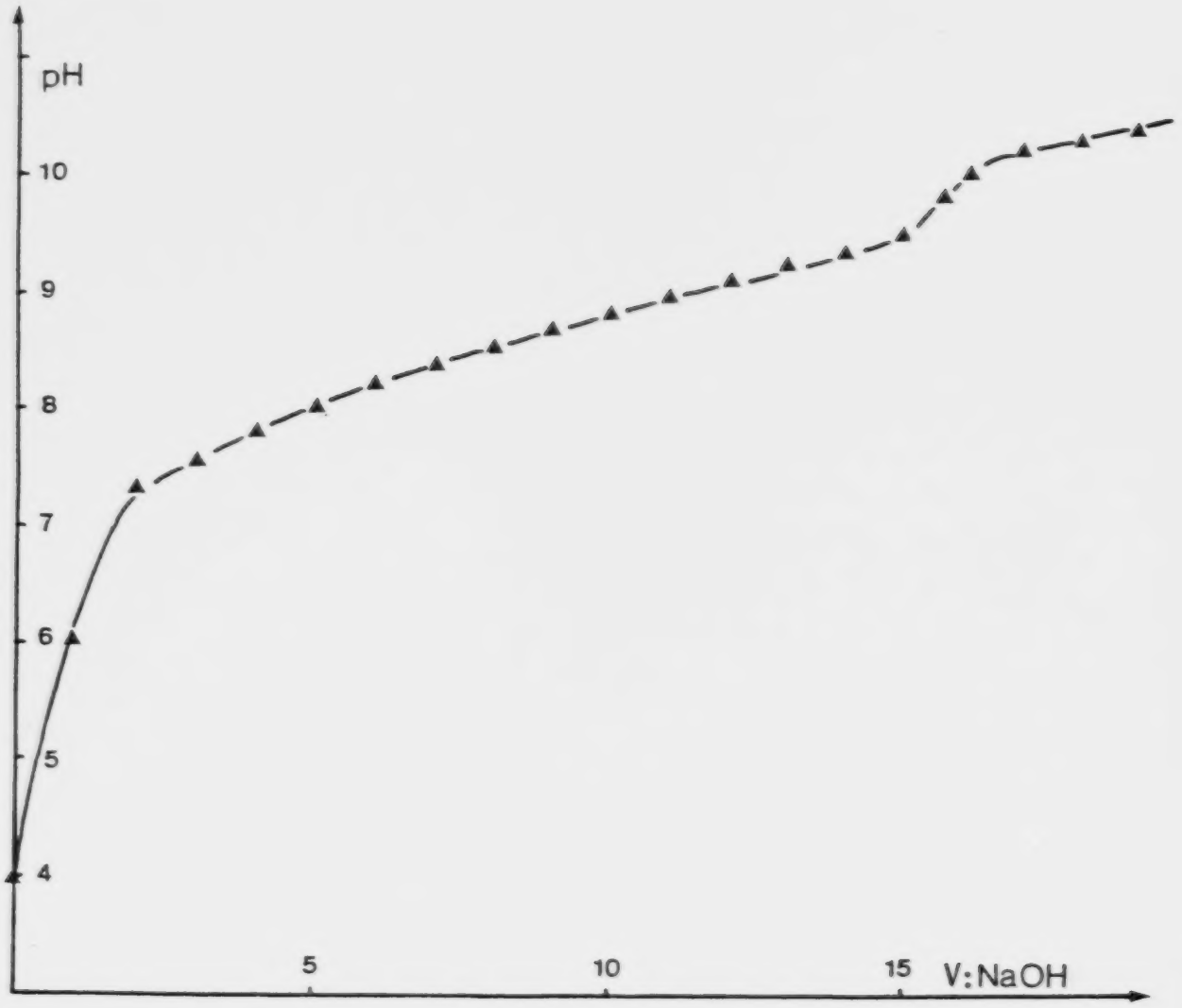

Fig. IIc : Titration of NH_4Cl againstNaOH

- end-point of neutralization (Volume and pH)
- and to calculate acid concentration and pKa of weak acids.

It is interesting to note that the experimental values are good but systematically lower than the values of the table. Two facts, unknown by the students should be considered :

1) The antimony electrode does not work very well for pH = 10. The right parts of the curves are a little erroneous. In that sense the obtained values after neutralization are a little too low and then the pH for end-points of titration are also lower than the expected values.

2) The antimony electrode gives a response that is not instantaneous : thus when the pH varies too rapidly, i.e. when neutralization is complete, a few minutes must be allowed to obtain the equilibrium.

3) The responses of the electrode is not theoretical.. Each one should be carefully standardized with different buffers, for example at pH = 4 (phtalate solution) at pH = 6,8 (phosphate solution) at pH = 9,2 (tetraborate solution).

After drawing their curves, the students were given a questionnaire. Questions were as follows :

1°) What do you think about the instrument?
2°) Do you think that precision is good enough?
3°) Is reading of the meter easy or difficult?
4°) What do you think about your curves? Compare them with those obtained with commercial instrument (Note : at the same time other students operated the same acid-base titrations with commercial instruments).
5°) What are the best quality and worse defect of the instrument?
6°) The price is about $ 50. What do you think now?

Answers were collected and analysed. Then a report was made based on student's answers and behaviour. This report was sent to Dr. K.V. SANE.

General comments -

The pH meter that was tested by some students and myself is simple and easy to use. The price is very attractive and I think that it is its best quality. It should be valuable also in college, nowadays, where money crisis also come in educationnal institutions. It is interesting for a pedagogical point of

view considering the two following facts :

- it is an excellent support for explaining the link between pH and potential : students are not always aware of this despite the fact they are teached a primary electrochemical systems.

- it is excellent for demonstrating that comprehensive chemistry can be made without a sophisticated and expensive apparatus. Some general concepts in chemistry can be deduced with instrument of low cost.

Concerning the students, it should be noticed that they were well aware of the price. Almost all of them considered that pH meter as sufficient for their level in chemistry in the first year in the University. They thought that provided a high precision is not needed for pKa of weak acids, this instrument is sufficient.

Conclusion -

The collaboration with Dr. K.V. SANE and his group does not follow the classical sheme, where developped countries imposes technology and know-how which is not always adapted for actual needs. In the present case India alone furnished good material, well adapted not only for developping countries, but also for our students. The role of teachers from the Université CLAUDE BERNARD was to give an evaluation both objective and independent, and also to contribute to the improvement of the instrument. French students used this mV-pH meter and found it valuable. I think that it could be beneficial for students from other countries developped as well as developping.

Acknowledgements -

The author thanks Pr. M. CHASTRETTE for encouraging discussions and gentle criticisms about manuscript.

TRENDS AND ISSUES IN INTERNATIONAL CHEMICAL EDUCATION

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As problems become apparent in the teaching of chemistry, committed instuctors attempt to find solutions. Thus issues are identified and trends developed. This is a continuing and evolutionary process. Some issues appear to be cyclic; they wax and wane during fairly distinct time periods. (e.g. the theory vs. application debate). Some appear to be continuous; they have existed for decades and seem to defy solution (e.g. how to effectively integrate, or at least relate, the theoretical and practical work). From time to time, truly new problems emerge (e.g. how to fully utilize microelectronics in instruction); these require trail blazing in chemical education.

Today, let us focus attention on eight of the current trends. Each grows out of a clearly identifiable need. Although there may be differences in degree, each transcends all educational levels (primary, secondary, tertiary and adult/continuing education) and each has relevance for countries in all stages of development. They can be introduced briefly in phrases that indicate their directions as follows:

Toward:

1. Lowering the costs of laboratory and field work.
2. Designing courses and curricula for general education.
3. Increasing the interdisciplinary content.
4. Coping with and utilizing the microelectronics revolution.
5. Developing more versatile examination and evaluation systems.
6. Improving the education and status of teachers.
7. Promoting research and advanced degree programs in chemical education.
8. Facilitating national, regional and international communication and cooperation.

1. LOWERING THE COSTS OF LABORATORY AND FIELD WORK

This workshop is directly devoted to Trend 1: Lowering costs in the laboratory and field. Developing effective equipment for the laboratory has commanded most of the attention. Other related questions that might be addressed as time permits could include some of the following: What new experiments that teach the important principles of chemisty at lower cost can be designed? Can the cost of chemicals be cut by using substitutes, lower grade reagents or semi-micro quantities? What new equipment is needed as fieldwork increases? How can we manage storage for the multi-day experiments required in the new interdisciplinary areas (e.g. environmental chemistry)? What a world of work there is to do for Trend 1 alone!

2. DESIGNING COURSES AND CURRICULA FOR GENERAL EDUCATION

Once the primary purpose of chemical education was to prepare a limited number of secondary school students for admission to the universities and university students for careers in chemistry. Thus we catered to no more than 15% of the students and ignored the large majority. This is no longer possible. All of our people enjoy the benefits and/or suffer the negative consequences of chemistry in everyday life. All have a need and a right to some understanding of chemistry and of scientific processes--to an operational everyday literacy in science. There are at least three groups, in addition to those who will become chemists, who require some education in chemistry. Together, they overlap to form the entire population. One group is comprized of those who

will draw on a knowledge of chemistry in their professional work (e.g. health scientists, engineers, agriculturalists). Another consists of all those who will be the managers, the decision-makers in the society (e.g. the prime ministers, legislators, industrial managers, university administrators, for examples). The third includes citizens in every walk of life who must make decisions and manage their lives with respect to foods, additives and substitutes, medications, sources of energy, protection of the environment, shelter, transportation, communication and a myriad of other factors with chemical bases that determine the quality of life and of the culture. Existing courses do not meet these needs: they cannot be successfully adapted since they were designed for entirely different purposes. New courses and approaches to teaching, perhaps modular in design, that are motivational and sufficiently relevant and articulate to promote public understanding of chemistry, of the potential and limitations of science and of cost/benefit tradeoff is essential. In this trend, we're moving toward the teaching of science to <u>everyone</u>, <u>every year</u>, from primary school through the first two years of higher education at least with the public at large as the ultimate target audience.

3. INCREASING THE INTERDISCIPLINARY CONTENT

Chemistry is increasingly viewed as the most interdisciplinary science, the central science, with ties to every critical area of human endeavor. For example, the health scientists turn to chemistry for new pharmaceuticals, better nutrition, or correc-

tion of chemical imbalances caused by organ transplants or those reflected in mental illnesses. Chemotherapy is effectively used in the treatment of cancer. The biochemicotechnological revolution in agriculture provides other examples. The fertilizers, the pesticides and the chemically-based irrigation and food processing systems are all examples of chemistry in action to help feed the world's growing populations. Artificial nitrogen fixation and man-enhanced photosynthesis are active areas of research that hold promise for the future.

Many more examples could be cited; the list is almost endless. Just let your mind roam through the images conjured by areas of our dicipline such as geochemistry, atmospheric chemistry, chemical oceanography, environmental chemistry, industrial chemistry, cosmochemistry, biochemistry, etc., and etc.

How do we bring these interdisciplinary aspects of chemistry into our classrooms and laboratories? And, in fact, how do we take our students out into the natural world where chemistry reactions abound? Good interdisciplinary courses and curricula require very demanding and sophisticated development, implementation and evaluation efforts. Teachers must be retrained and examinations altered. Leadership must be provided by the chemists with help from the educationists. Productive research and effective decision-making both require a broadening of chemistry content for the future scientist and for the citizen.

4. COPING WITH AND EFFECTIVELY UTILIZING MICROELECTRONICS

A relatively new but rapidly advancing influence on instruction in chemistry is the impact of microelectronic devices such as the microcomputer, electronic balances and pH meters. The high technology revolution is here to stay. Computers and robotics are changing the world of work, the daily lives of millions and millions of people and they most assuredly are changing the world of chemical education.

In chemistry, computers are used extensively in the more developed countries now and are beginning to appear in developing nations as well. In instruction they are used for interfacing with laboratory apparatus, to promote comprehension of the three-dimensional geometry of molecules and of dynamic systems and reaction mechanisms through graphics, to simulate experiments, analyze data, manage complex calculations, for drill and practise, to manage assessment and to handle the intermiable record-keeping. The hardware is increasing in versatility and decreasing in cost. Software is the limiting factor. Creative chemical educators are needed as never before to generate effective instructional software.

5. DEVELOPING MORE VERSATILE EXAMINATION AND EVALUATION SYSTEMS

Wherever external examinations that determine a young person's future exist, teachers are under pressure to prepare students for the examinations. If the examinations require "pure" chemistry and the recall of facts, the teaching will be tailored to these goals. With the growing convictions of the importance of inter-disciplinary content, of social relevancy, and of the development of such intellectual skills as problem-solving, application,

interpretation and decision-making, the examinations must be dramatically altered in content and in style to reflect the new learning goals. The teaching will change quickly if new knowledge and thinking is expected from students in order to score well on these examinations. But how can these changes be implemented? Who will provide the leadership for change? Who will supply the ideas and shape the questions? This type of effort draws few professional rewards.

Other changes in the evaluation system are needed and inovators are at work. Examples can be found in continuous evaluation/-assessment systems, Keller-type mastery teaching and the use of the computerized question banks that promote flexibility, individualization and varied-yet-balanced assessment instruments.

6. IMPROVING TEACHER EDUCATION AND STATUS

The youth of a nation is its most valuable resource. How then can concern for the quality of teaching and for the care and encouragement of competent teachers have such a low priority in nation after nation around the world? New modes of teacher training are desperately needed and being explored in some instances. Incentives to enter the teaching profession and ways of rewarding excellence are being tested. Recognition that a nation is at risk when the quality of its teaching is declining is finally dawning on national leaders and the public at large. To be a competent teacher at secondary or tertiary level requires as many years of higher education as the much higher paying profession of medicine, engineering, or law. The monetary and

social rewards must be similar in fairness to the good teachers now in the classrooms and to attract a strong new generation of teachers. This is a tall order since it will require social change, revamping of budgets, new methods and materials for teacher training and a host of other actions. But it must be done and it must move from the very small beginnings now evident to large scale programs within this decade.

7. PROMOTING RESEARCH AND ADVANCED DEGREES IN CHEMICAL EDUCATION

A strong base of research in chemical education is needed; a comparatively weak one exists now, but chemical education is growing in recognition as a research area. This can be further facilitated by the development of more strong master's and doctoral degree programs in chemical education. More funding is urgently needed for research. There is evidence now of growth in sophistication in research design and techniques, and more centers where chemical education is recognized as a sub-discipline of chemistry, an international exchange of products, experiences and ideas through the literature and in seminars, conferences and study tours. This is happening in Israel, in Australia, in Yugoslavia, in Thailand, in the United Kingdom, and in the United States, for examples. Advances in chemical education are heavily dependent on research and development work. Let there be no apologies for the developmental base for much of our research and advanced degree thesis work. Instead, let this groundswell grow and help it to thrive.

8. FACILITATING NATIONAL, REGIONAL, AND INTERNATIONAL COMMUNICATION AND COOPERATION

During the past decade, there has been steady growth in chemical education programs in such established organizations as the American Chemical Society, ASC, and the International Union of Pure and Applied Chemistry, IUPAC, and through the United Nations Education Scientific and Cultural Organization, UNESCO. New organizations with chemical education interests are emerging. Examples are the International Organization for Chemical Sciences in Development (IOCD) and Chemical Research Applied to World Needs (CHEMRAWN). The programs of these and other organizations are growing in strength and variety (e.g. newsletters, seminars, workshops, conferences, the publishing of monographs and source books, the exchange of curricula and teaching materials as sources of ideas and experiments). This workshop provides a prime example through the exchange of ideas and materials from both the developing and developed world, and in the cooperation of national and international organizations such IUPAC and UNESCO.

These eight trends are global. Each is apparent in most nations irrespective of stage of development. They differ in degree of urgency, of course. For example, Trend No. 1, "Lowering the Costs of Instruction" is a high priority in many developing countries but it is of importance, too, in the more developed countries as is clearly evident in this workshop. Trend No. 4, "Coping with and utilizing microelectronics" is strongly impacting chemical education in many of the industrialized

nations, but other countries are experiencing the initial vibrations of change.

It will be interesting to compare these trends with those apparent five years hence. How many will continue to develop. Will some have disappeared? Is real progress evident? It should be interesting to monitor change and to determine what the future holds for chemical education.

LOW COST CATION-EXCHANGER FROM WATER HYACINTH

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ABSTRACT

The commercial varieties of ion-exchangers such as the acid type RSO_3H and $RSCOOH$ are not readily available for undergraduate students in chemistry in remote rural colleges of Bangladesh for experiments involving ion-exchange phenomenon. Water hyacinth has been found to absorb metal ions to a great extent and it was therefore considered appropriate to determine the nature of metal uptake. While some transition metals of high charge are irreversibly absorbed by the plant, some metal cations such as those of alkali, alkaline earth and divalent cations of transition metals appear to strike an equilibrium process in the plant cells and exhibit exchange phenomenon under appropriate conditions of pH and concentrations. Both fresh and dried plant function as ion exchanger. The capacities of some metal ions including those for H^+ ion were measured according to conventional methods. The stems of the fresh plant were cut into small pieces and dried in the sun before subjecting to either batch or column methods. The uptake capacity was initially small but could be improved by pretreatment.

The experiments with anions seem to depend on certain conditions not yet fully ascertained. However, dried water hyacinth appear to function as a better cation exchanger but is less efficient as anion exchanger. The difference in behaviour has been explained on the basis of the predominance of acid groups in the polymer forming the cell structure suitable only for cation exchange and the cessation of assimilation phenomenon in the dried plant which has no need for phosphates, nitrates, chlorides etc.

INTRODUCTION

The cost of commercial ion-exchange resin for water purification and for analytical chemistry experiments is too high in Bangladesh to be a tool for general use and particularly for undergraduate teaching of practical chemistry. Even for graduate level the use of imported ion-exchange resins is extremely limited because of prohibitive price and spoilage due to mishandling.

In course of a Research Project sponsored and financed by the Commonwealth Science Council, London entitled "Management of Water Hyacinth", we investigated into the various aspects of the utilization of the aqueous plant growing luxuriantly with highest rate of proliferation. Water hyacinth is considered as a nuisence and a menace to rice fields, fish culture ponds and breeding grounds for mosquitoes and other insect pests. However, among many ways of its economic utilization we also investigated the fantastic property of water hyacinth for absorption of chemical species, particularly the metal ions from aqueous ecosystems (1, 2, 3). We made an extensive survey of the utilization of

this property of water hyacinth and found that this miracle aquatic plant can be used with appropriate technique for the purpose of :

(1) Pollution control of industrial effluents.
(2) Polishing of sewage discharge effluents.
(3) Water purification in small ponds and tanks by proper management.
(4) Ion-Exchange materials for experiments in analytical Chemistry.

In order to investigate the metal absorption characteristics of the different parts of water hyacinth (root, stem and leaf), experiments were carried out by complexometric titrations, atomic absorption spectrometer and perticle induced x-ray emission method. The survival pattern of fresh water hyacinth in presence of high concentrations of metal ions were also determined and the limit was expressed in terms of Tolerance Index (TI). The TI parameter gives a measure of the limit of uptake of metal ions by 100 g of fresh water hyacinth plant. In dried water hyacinth the usual procedure for the ion-exchange capacity was followed in terms of mg/g.

The existence of ionic balance in fresh water hyacinth with respect to some metal ions was proved by deprotonation reactions indicated by pH changes in the aqueous metal salt solutions (4, 5).

We consider that the dried water hyacinth stems can be introduced as a very cheap material for ion-exchange experiments in the undergraduate level.

MATERIALS:

Only the stems of the fresh water hyacinth plant were chopped into small pieces and dried in the sun until the moisture content was reduced to minimum (15-20%). The naturally present H^+ possibly as-COOH groups, has to be maintained for the efficient use as ion-exchanger.

EXPERIMENTAL

Both batch and column method have been carried out with several metal ions individually and also in mixtures of known concentrations. Attempts for separating certain metal ions from the absorbed materials have also been made. The batch method suffers from the disadvantage that dried pieces of water hyacinth stems float on top of the solution which has to be stirred. However, a properly packed column serves better since the fluid flow can be easily controlled at the desired rate. The tall

cylindrical separatory funnel has been found most suitable in view of the visual examination of a small volume of the liquid at the bottom of the funnel.

RESULTS

The cation uptake in dried water hyacinth are given in Table 1. The results were obtained with unprocessed dried water hyacinth. Processing with 2N HCl improved the efficiency which is recorded in Table 2.

Table 1. Cation uptake in dried water hyacinth.

Ions	pH	Column method mg/g	Batch method (overnight) mg/g
H^{+}	3.2	0.41	0.36
Cu^{+2}	4.2	0.74	0.69
Ca^{+2}	4.9	0.20	0.10
Na^{+}	6.7	0.10	0.54
Mg^{+2}	5.6	0.52	0.42
Ni^{+2}	5.5	0.81	0.91
Zn^{+2}	5.3	0.62	0.35

The uptake of metal ion increased on pretreatment with 2N HCl and the water hyacinth bits made free of HCl by washing with water.

Ions	Absorption mg/g 1 hour	2 hours	3 hours
Cu^{+2}	3.5	9.4	6.0
Ni^{+2}	4.9	5.2	2.0
Zn^{+2}	9.6	9.8	6.4
Cd^{+2}	7.4	8.2	4.3
Co^{+2}	0.9	1.5	0.6

The ionic equilibrium phenomenon is evident from the results and particularly observed in respect of alkali and alkaline earth metal ions. The uptake of Ca^{+2}, Mg^{+2}, K^{+1} indicated a dyuamic process of equilibria and in presence of large excess of Ca^{+2} and Mg^{+2} ions, the depletion of potassium already present in water hyacinth takes place.

The experiments with anions seem to depend on certain conditions not yet fully determined. Dried water hyacinth appear to function as a better cation exchanger and is much less efficient as an anion-exchanger. The difference in behaviour can be explained on the basis of the polymer constituent with acidic groups in the cellular structure which has the capacity to exchange H^+ ions but is incapable of metabolic processes involving uptake of phosphates, nitrates, chlorides in the dried form.

The deprotonation reactions of fresh water hyacinth in presence of aqueous solution of metal ions result in the decrease of pH as observed in previous experiments.

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LOW COST MAGNETIC BALANCE

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ABSTRACT

Magnetic susceptibility and magnetic moment measurements constitute fascinating experiments at the undergraduate levels in order to determine the structural peculiarities of inorganic complexes. While the modern costly electromagnets together with power pack and other necessary components and control mechanism for sophisticated work is cost prohibitive, we have designed and fabricated a modified form of the old Curie-Cheneveau magnetic balance using a movable permanent magnet of flux density about 4000 gauss. The magnetic balance, in a glass panelled box consists of a metallic copper beam suspended from the top of a cylindrical brass casing by a length of phosphorbronze wire. The movement of the magnet is controlled by a lever from outside the glasspanelled box. The sample in a glass tube is suspended in the middle of the pole pieces from the tip of the long arm of copper beam and the circular movement of the permanent magnet drags the sample in the glass tube with force proportional to the magnetic moment of known amount of the substance and is indicated by the torque in the phosphorbronze wire. This is recorded by the reflection of a suitably placed paper scale in a small mirror affixed at an appropriate distance of the wire. The scale readings between the to-and-fro movements of the magnet is proportional to the magnetic susceptibility and is calibrated with the help of a substance of known magnetic moment.

INTRODUCTION

In the graduate and undergraduate levels of chemical education it is necessary to teach the interpretations of the properties of substances in terms of their molecular and electronic structures. One of the important means to achieve this objective is the modern trends to use high cost sophisticated equipments. But the same objective could be accomplished by devising low cost simple equipments for the measurement of magnetic moments. Such an equipment is robust, need only few components to build, is easy to operate and can be maintained at almost Zero

cost for years together. Great varieties in designs and construction of magnetic balances are possible and the students could have the freedom and choice to manipulate the set up according to convenience and imagination. This is one field where manipulative and cognitive skills of students could be developed without much expenditures.

The magnetic nature of substances has been a source of curiosity and a source of enjoyment to common people and students and many fascinating experiments based on magnetic devices have produced far reaching effects in the advancement of scientific education in particular. In the field of Chemistry magnetic measurements have been applied to study the property of catalysts, free radicals, chemisorption, metals and alloys, polymer characterisation and above all for the determination of the nature of bonding systems and structures of inorganic[1] and some type of organic compounds[2]. Useful informations about the reaction kinetics and reaction processes have also been obtained by magnetic measurements with the help of simple devices[3]. The close proximity of paramagnetic ions in substances may lead to electronic interactions which could be best studied by magnetic measurements since such interactions give rise to increased or decreased magnetic susceptibility. For instance iron and some of its compounds show ferromagnetism whereas hydrated ferric ammonium sulphate in which ferric ions are widely dispersed show only low values of magnetic behaviour[4]. Particularly the investigations of magnetic properties has made a special contributions and impact in the advancement of coordination Chemistry. Magnetic measurements are used for indicating the degeneracy and nature of the ground state of the transition element species leading to informations regarding the coordination number and stereochemistry of inorganic complex compounds.[5,6,7]

DESIGNS OF EQUIPMENT

Numerous techniques have been adopted and many novel designs and devices for magnetic measurements have been reported. Both permanent and electro-magnets of various field strengths have been used for simple demonstrations, and measurements. Although magnetic balances of high field permanent magnet are inexpensive but can be operated only at one field strength. These are most suitable for instructional purposes

at undergraduate level but may not be suitable for research involving variations of field strength and temperature. Magnetic balances for research purposes are, therefore generally constructed with electromagnets having the variable field strength with appropriate arrangements of power supply, current stabilizers and thermal arrangements. These are costly equipments and are available from commercial suppliers but cheaper varieties could be fabricated by enthusiastic students.

Demonstration equipments for magnetic properties have been fabricated and quite fascinating experiments have been designed for undergraduate level. For instance, a magnet of 3000 gauss and a discarded double beam balance coupled together as a magnetic balance gave quite satisfactory results.[8] Experiments with a magnet placed in a glass dish containing thin layer of water indicated diffusion of coloured solution of a magnetic substance in between the pole pieces when a drop of solution was placed near the magnet.[9] The paramagnetic and diamagnetic properties of solutions were also measured by means of a magnet of 5000 gauss by appropriate adjustments of the tube containing the solution.[10]

Quite a number of novel devices for magnetic measurements have been reported indicating the varieties that have been incorporated for the simplification of instrumental techniques including the one in our laboratory. A simple horse shoe magnet was used to show the paramagnetic nature of substances and a 45 lb pull strong magnet indicated both the paramagnetic and diamagnetic behaviour of solids and liquids by suitable arrangements.[11,12] An equipment was also devised to determine the paramagnetism by suspending the sample in a tube with a float of styrofoam or cork in a liquid within a larger tube placed in a magnetic field.[13]

TEMPERATURE MEASUREMENT DEVICES

Incorporation of temperature measurement devices with magnetic balances is rather a little complicated and most simple magnetic balances are constructed for measurements at ambient conditions. Although without temperature dependent studies sometimes the prediction of unpaired electrons, oxidation states and stereochemistry of magnetic substances may suffer from inaccurate inferences but can be dispensed with for undergraduate level without much disadvantage. However, simple apparatus have been designed with heated chambers for magnetic susceptibiligy measurements at variable temperatures[14,15,16] Expensive equipments

for use with gas circulation from liquid nitrogen storage flask for low temperature measurements or more sophisticated Hitachi - Perkin-Elmer models for variable temperature equipment using nmr machine is normally most expensive.

A variable temperature Faraday Magnetic Balance[17] for the temperature range 80 - 300°K although made in the laboratory is unsuitable as a low cost equipment and much complicated in design and operation requiring corrections for, diamagnetic substituents from Pascal's constants.[18]

Even for the purpose of demonstration of magnetic properties, the large expensive magnets and fragile system of suspension of sample may be dispensed with in favour of small magnet of about 90 - 100g which is directly weighed on a balance pan and the sample in a glass tube is held fixed with a clamp in between the poles of the magnet. The change in the weight of the magnet is proportional to the magnetic susceptibility and when compared with that of a standard such as $HgCo(CNS)_4$, the magnetic moment can be easily calculated from equation[19].

$$\chi_s = \frac{\Delta W_s - \Delta W_B}{W_s} \times \frac{\chi_{ref}}{\frac{\Delta W_{ref} - \Delta W_B}{W_{ref}}}$$

where χ_s = Magnetic susceptibility of unknown sample.

ΔW_B = Weight change of the magnet in the presence of the empty tube

ΔW_{ref} = Weight change of the magnet in the presence of the standard in the tube

ΔW_s = Weight change of the magnet in the presence of unknown sample in the tube.

W_s = Weight of the sample in the tube

W_{ref} = Weight of the standard in the tube.

STUDY OF REACTION RATES

A low cost Faraday Balance was claimed to be devised for studying the effect of strong magnetic field on reaction rates.[20] Rates of reduction of Fe_3O_4 to Fe and Fe O to Fe were studied with and without the applied magnetic field.[21,22] Using the technique of thermomagnetic analysis Hyman and Rowe studied the effect of an applied magnetic field on a reaction by measuring the weight changes of the sample with and without the field at different temperatures.[23]

NMR DEVICES FOR MAGNETIC MEASUREMENTS

Evans[24] originally described the use of nuclear magnetic resonance spectrometer for magnetic measurements particularly in solutions. Experiments have been devised by various workers[25] based on frequency shift of operation in nmr spectrometer. For instance, of the change of geometry of Nickel - Schiff base complexes from octabedral to square planar or the equilibrium mixture of the two in solutions could be determined by magnetic measurements in m-xylene at several different temperatures[26,27]. The kinetics of ligand rearrangements by microtechnique of nmr have been reported[28]. However the Evans nmr method is supposed to give erroneous results for either μ_{eff} or equilibria unless the variation in solution density with temperature is taken into account. Moreover, the cost involved in establishment, maintenance and operation is prohibitive.

But simple equipments based on the relationship of frequency shift ratio of an oscillator containing sample in glass tubes can be constructed at a very low cost[29,30]. An inexpensive equipment using electronic counting technology as a superior alternative to Gouy method has been developed for measuring the paramagnetic property of solid samples[31]. We have also assembled such an equipment in our laboratory and the measurements and other related investigations are in progress the effective magnetic moment μ_{eff} Is related to frequency shift of the oscillator by equation

$$\mu_{eff} = \frac{KT \cdot Mr}{m} \cdot \frac{\Delta f}{f_o} \quad \text{Bohr Magnetons}$$

where m = mass of the sample in the tube
Mr = relative formula mass
K = Calibration constant
T = temperature (K^o)
f_o = frequency of the oscillator without sample.
fs = frequency of the oscillator with sample.

$\Delta f = f_o - f_s$

CURIE-CHENEVEAU TYPE BALANCES

For quite sometime we have been using a modified Curie-Chenevean magnetic balance which is a low cost equipment constructed with a permanent magnet of about 4000-5000 gauss[32]. We have obtained remarkably good results for the spin only values of magnetic moments and

published a good number of papers both in the national and international uournals of chemistry. The balance is based on the principle that if a hody of mass 'm' and mass susceptibility χ_g is placed in a field produced by a magnet of intensity H, the force 'f' that tends to move the body perpendicular to the direction of the field is given by

$$f = \chi_g . m . H . \frac{dH}{dx}$$

Force f = o when H=O i.e. when the magnet is at a great distance from the body. The force f is also = O when the space variation of the field dH/dx = O. This shows that the force is zero when the body is at the centre of the pole pieces of the magnet. There are two points at which the product of the field by its gradient dH/dx is maximum and the body experiences maximum deflection which is proportional to the product of the magnetic susceptibility and the mass of the substance.

The magnetic susceptibility of a sample is determined by comparing the deflection due to the substance with that due to a standard (Mohr's salt) of known magnetic susceptibility using the equation.

$$\chi_g = \frac{m_M(\theta_s - \theta_o)}{ms(\theta_m - \theta_o)} \times \chi_o$$

where χ_g = magnetic mass susceptibility of sample
χ_o = magnetic susceptibility of Mohr's Salt
m_M = weight of Mohr's Salt
ms = weight of the sample
θ_M = deflection due to Mohr's Salt
θ_s = deflection due to sample
θ_o = deflection due to empty tube.

The balance consists of a torsion arm or beam made of copper suspended by a fine wire of phosphor-bronze from a brass hook. A glass tube containing the substance is suspended at one end of the torsion beam and the other end of the beam, suitable copper riders are placed to maintain the balance in the horizontal condition. A vertical copper strip is dipped in liquid paraffin contained in a beaker to dampen the movement of the arm. The phosphor-bronze wire is encased in a brass tube to protect it from air draft and the entire equipment with the magnet is kept in a glass panelled wooden box. The movement of the

magnet is operated from outside by means of a gear. The magnet was displaced along a circular path and the movement of the torsion beam with the sample was followed on a scale in the form of an arc which was illuminated by an electric bulb and the scale readings in the mirror were observed through a telescope (Fig.1). Clean, dry thin pyrex tubes of about

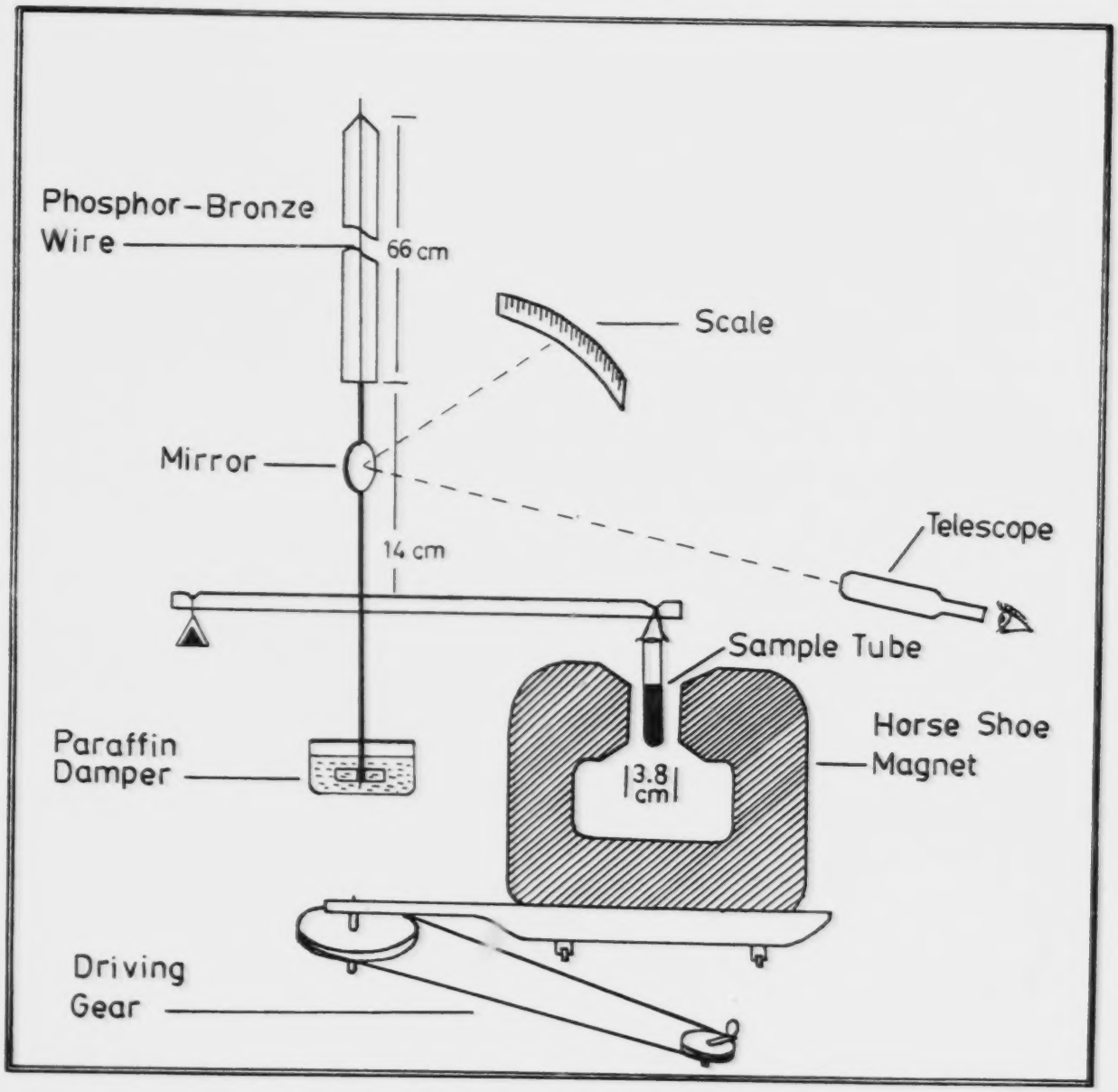

FIG. 1. MAGNETIC BALANCE

7 Cm length and 3 mm id were used. The tube was first weighed empty and suspended through the copper torsion arm by means of a fine thread. The magnet was moved very slowly. The deflection of the torsion beam from its equilibrium position was followed by the telescope-mirror-scale arrangement. The movement of the magnet as continued slowly till the scale read a maximum deflection and similar maximum deflection was also noted when the magnet was moved to the reverse position. The process repeated 3-4 times. Similar readings were obtained by filling the tube with samples and the standards of accurate weights. The mass susceptibility of Mohr's salt $\chi_o - (T + 1) = 9500 \times 10^{-6}$ CGS units was chosen as the standard.

ELECTROMAGNETIC BALANCE

The results obtained by the permanent magnetic balance were compared with those obtained in a sophisticated electromagnetic balance consisting of power supply unit model Alpha AL 7500PS, current stabilizer, water cooled electromagnet and the balance supplied by the Federal Pacific Electric Co, U.S.A. The electromagnet is calibrated by using Mohr's Salt or $HgCo(CNS)_4$ as standard and varying the field strength with the current in Ampres. The gram susceptibility χ_g of sample was calculated from the equation

$$\chi_g = \frac{2lP}{H_1^2 x m x 1.018}$$

where H_1 = magnetic field (gauss)

l = length of the sample in the tube (Cm)

m = mass of the sample.

P = increase in weight of the sample (mg).

Or $$\chi_g = \frac{K_2 V + \frac{2gl}{H^2} \cdot F'}{m}$$

K_2 = susceptibility per unit volume of the displaced medium

V = volume of the tube filled with sample (c.c.)

g = acceleration due to gravity

l = length of the specimen (Cm)

H = field strength (gauss)

m = weight of the sample (g)

F' = (F - D) in g

F = Observed pull exerted on the sample (g)

D = pull exerted on the empty tube (-g) since glass is a diamagnetic substance D is -ve.

The two results on various substances are given in the Table below.

Measurement Temperature = 28 - 30°C.

Sample	Magnetic Moments BM	
	Permanent Magnetic Balance	Electromagnetic Balance
$CuSO_4, 5H_2O$	2.01	1.98
$Ni(NO_3)_2, 6H_2O$	3.13	3.01
K_2SO_4, $Cr_2(SO_4)_3, 24H_2O$	3.84	3.87
$CoCl_3.6H_2O$	4.98	4.88
$MnSO_4.\ H_2O$	5.92	5.96
$Co(Py)_2Cl_2$	4.85	5.01
$Co(Py)_2Br_2$	4.62	4.70
$K_3Fe(C_2O_4)_3.3H_2O$	5.81	5.96

The results are in good agreement with those found in literatures.

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A SIMPLE AND VERSATILE INJECTION VALVE FOR FLOW INJECTION ANALYSIS.

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and
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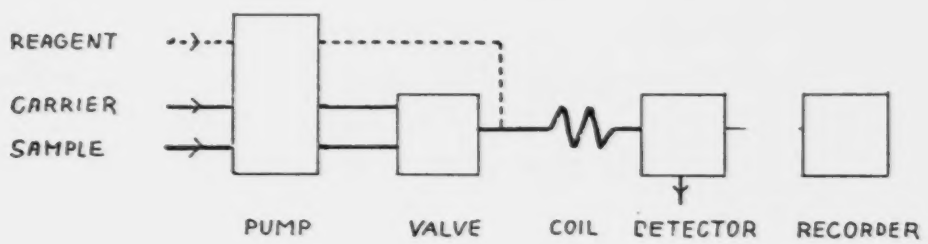
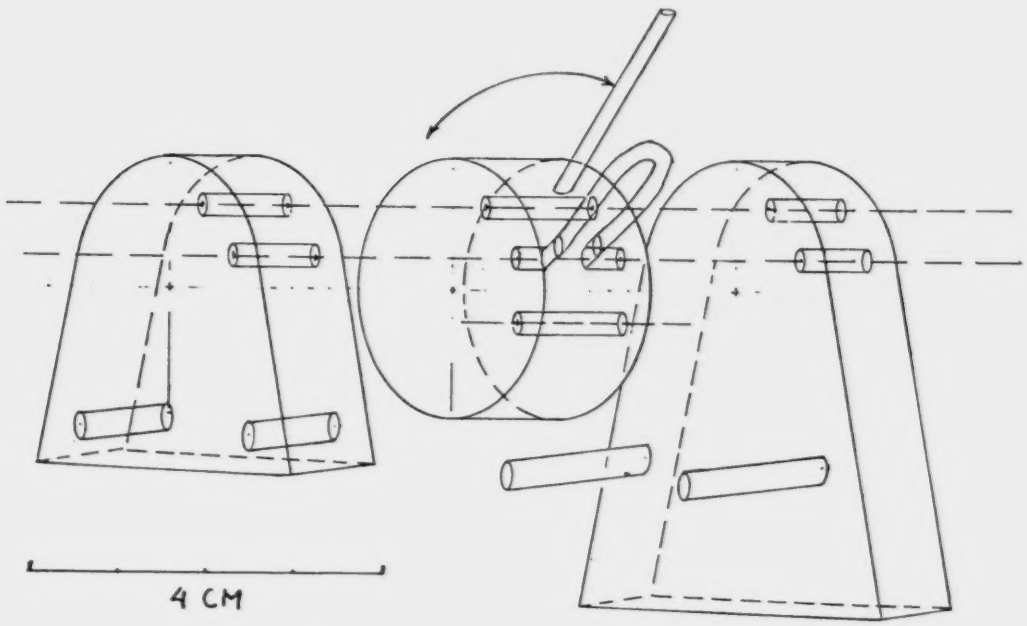
Flow Injection Analysis, FIA, is a simple technique for performing a large number of analytical (e.g. photometric or electrometric) determinations in a short time (30-150 determinations/hour) with a minimum consumption of sample and reagents. In its most common form a FIA system consists of a peristaltic pump, a few meters of 0.5 - 0.8 mm i.d. polyethylene tubing, some plastic tube connectors, an injection valve, a detector, and a recorder:

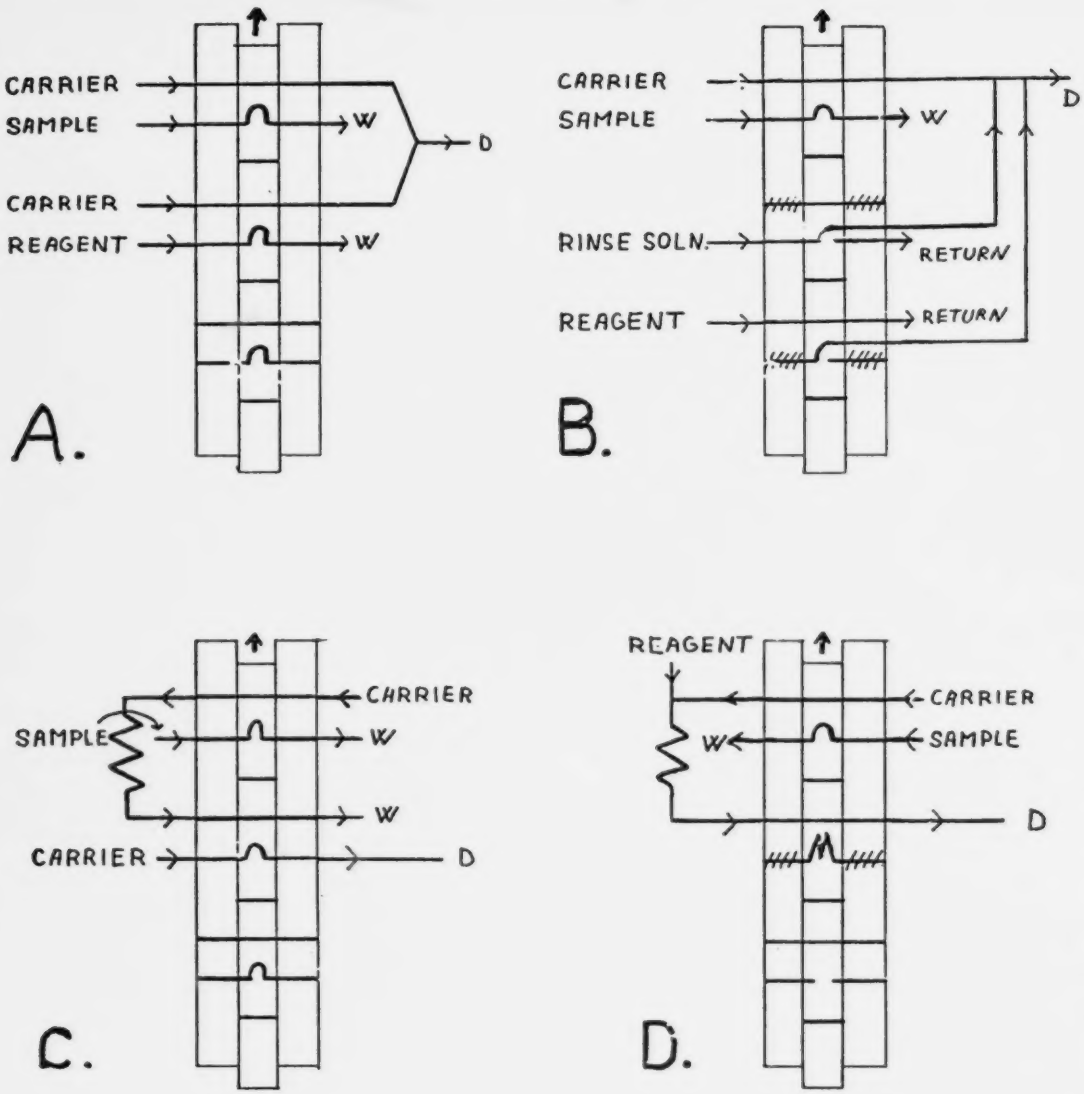


The versatility of a FIA system can be greatly improved by using a multichannel, three-layer or two-layer fast-switching injection valve.

The valves are constructed from Plexiglas and Teflon (or PVC) and can be made locally. Streams are directed by switching the valve between two positions, manually, magnetically, or pneumatically. If exact timing is required, switching may be done with the aid of a stop watch or a simple electronic timer.



Exploded view of three-layer valve. Only one channel shown. The outer stationary parts are Plexiglas, the central rotor is Teflon. The sample loop is a suitably chosen length of polyethylene tubing.



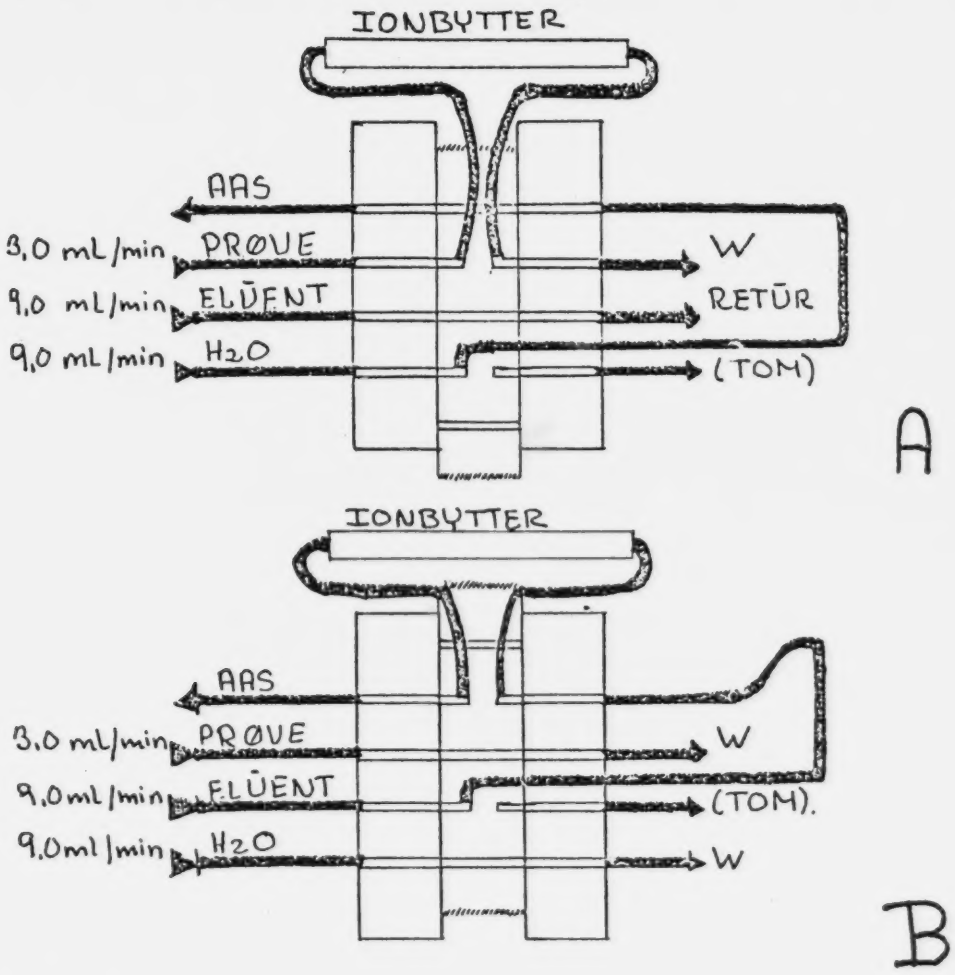
Three-layer valve with three channels shown in sampling position.

A. Simple injection. Merging zones configuration for minimizing reagent consumption.

B. Alternating streams configuration. Has been used for turbidimetric determination of sulphate as $BaSO_4$ and for determination of high concentrations of phosphate by molybdenum blue method.

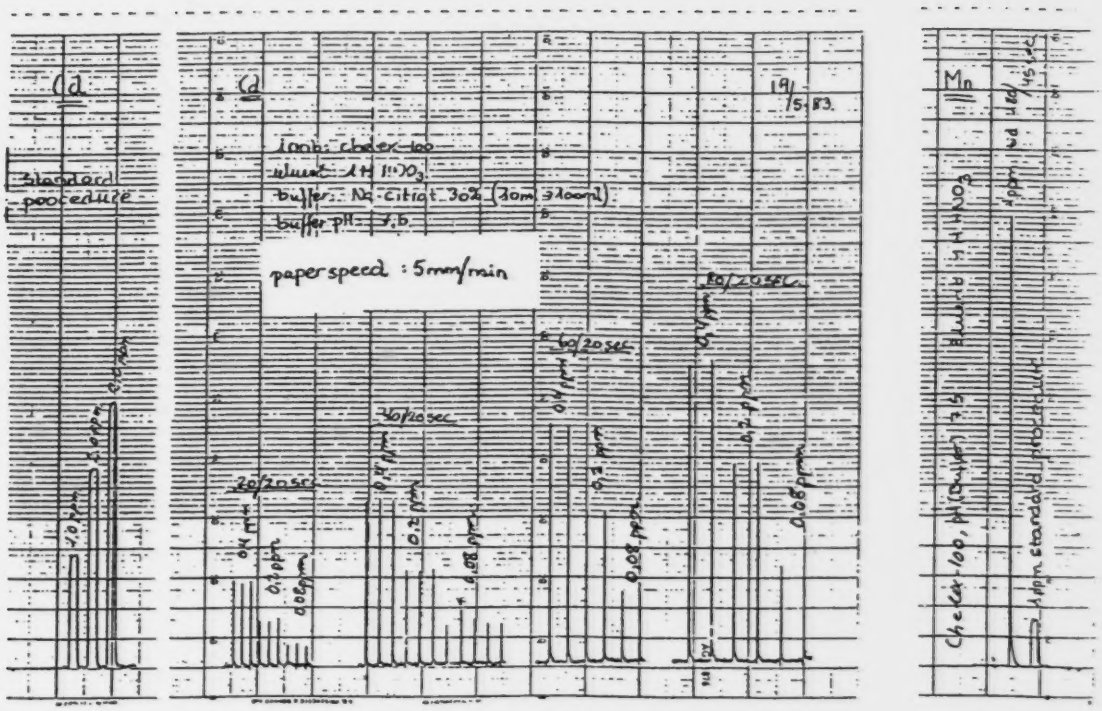
C. Zone-sampling configuration. Involves resampling after dilution. Has been used for AAS-determination of high concentrations of calcium in plant digests.

D. Zone-trapping configuration. After mixing with reagent the sample is trapped for a fixed time before further transport towards detection. Has been used for slow analytical reactions such as determination of ammonium at the ppb-level by the indophenol blue method and of silica by the molybdenum blue method.



Ion exchange preconcentration. Three-layer valve. In the concentration step the sample is adsorbed on a mini ion-exchange column for a definite time (1-2 min). In the elution step the adsorbed species are eluted counter-currently towards the detector. The concentration factor is determined by the ratio concentration time/elution time.

This procedure has been used for determination of heavy metals by flame AAS (Chelex 100 or Amberlite IRC 50 cation exchangers) and for determination of phosphate in the ppb-range by the molybdenum blue method (Bio Rad AG 2 X8 anion exchanger). Concentration factors up to 18 have been obtained in both methods.



Determination of cadmium and manganese by flame AAS using three-layer valve for ion-exchange preconcentration. Concentration factors as a function of the ratio concentration time/elution time.

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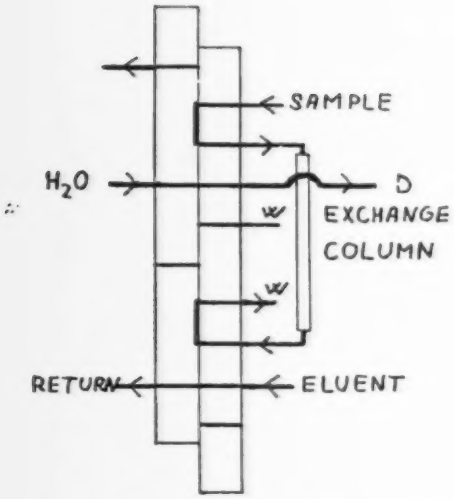
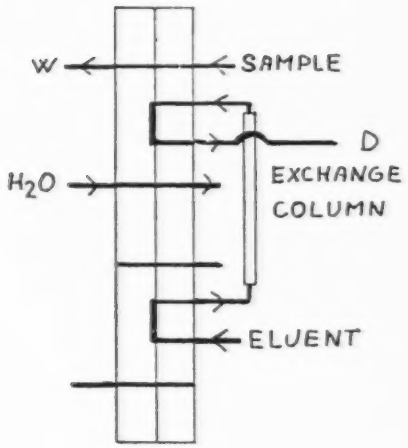


CONCENTRATION

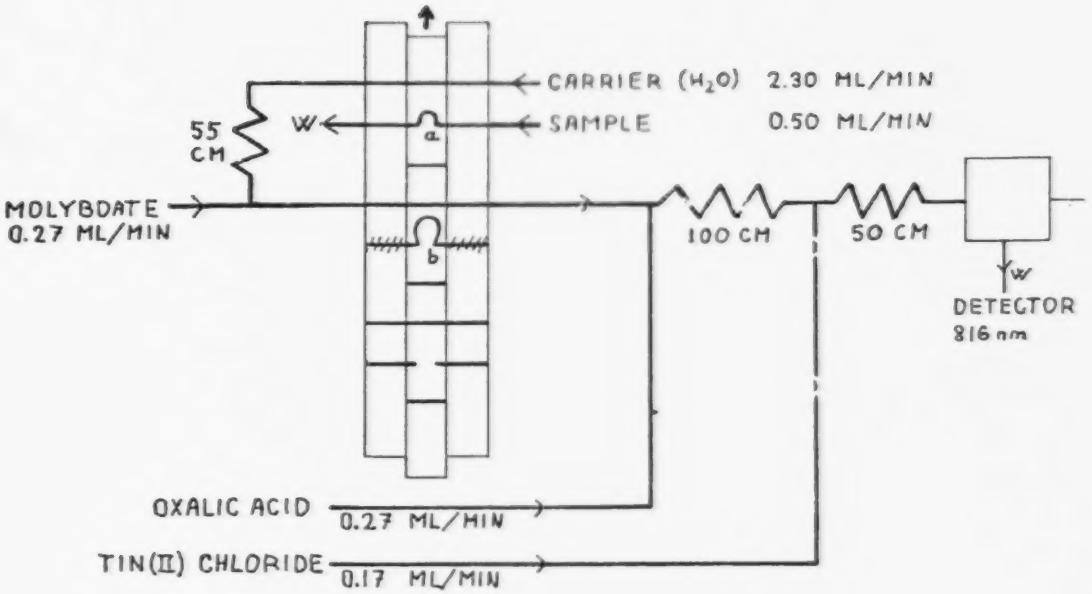


ELUTION

Two-layer valve used for ion-exchange preconcentration procedure. Analytical principle and performance are the same as for the three-layer valve.

The two-layer valve may be used for some of the procedures illustrated for the three-layer valve. In addition the two-layer valve offers other possibilities, such as timer determined sample size and sampling alternating between different sized loops and thus increasing the analytical determination range.

These configurations are presently being tested experimentally.



Flow diagram for determination of silica by molybdenum blue method and zone-trapping procedure.

All tubing is 0.80 mm i.d. polyethylene. Loop (a) is 15 cm (75 µl) and loop (b) is 100 cm (500 µl).

Sampling/reaction time: 120 sec.

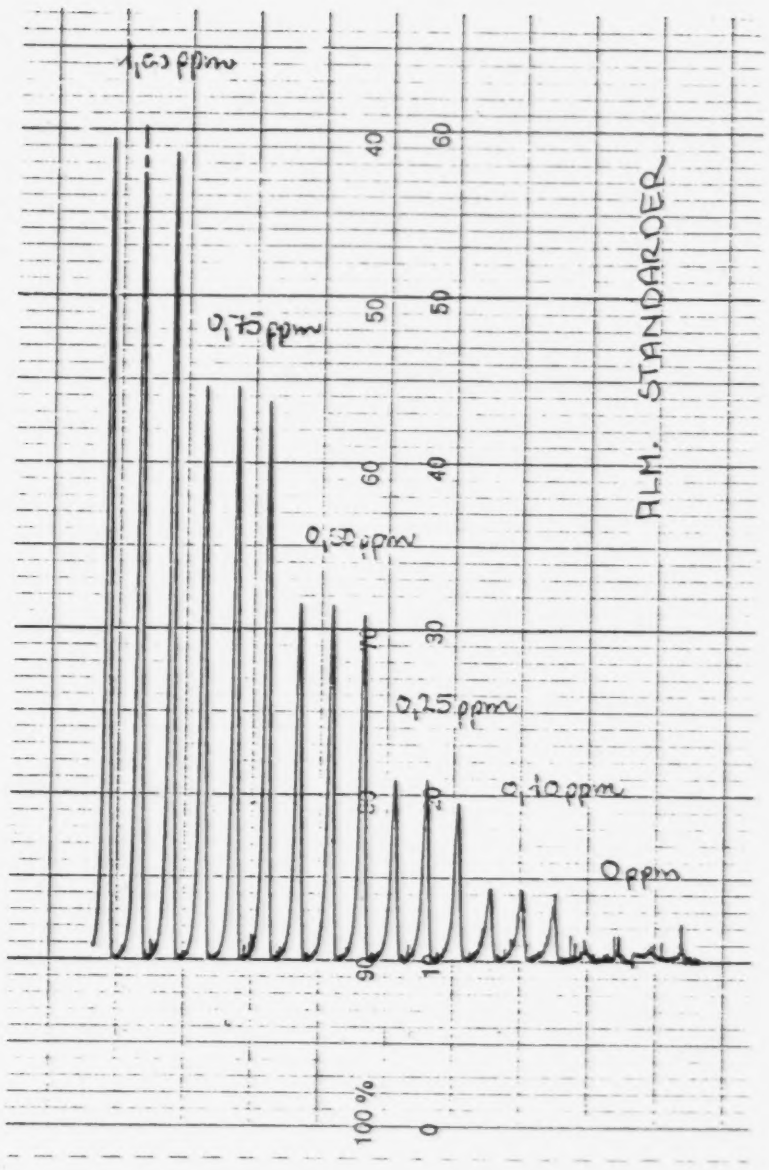
Introduction/determination time: 24 sec.

Reagents:

Molybdate: 11.12 g $(NH_4)_6Mo_7O_{24},4\ H_2O$ is dissolved in 360 ml H_2O. 140 ml 2 N H_2SO_4 is added.

Oxalic Acid: 7% in water.

Tin(II) Chloride: 0.10 g $SnCl_2,2\ H_2O$ plus 1.00 g hydrazine sulphate is dissolved in 400 ml H_2O. 14 ml conc. H_2SO_4 plus H_2O to 500 ml is added.



Signals obtained for 0.10-1.00 ppm standard solutions of silica. The 1.00 ppm signal corresponds to ~0.06 absorbance.

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Zone-trapping procedure:
F.J. Krug et al., Anal. Chim. Acta, in press.

Ion exchange preconcentration procedure:
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Two-layer valve procedures:
Are being tested, to be published.

MODULAR SYSTEM WITH OPERATIONAL AMPLIFIERS FOR MEASUREMENTS IN CHEMISTRY

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Introduction

An important part in modern instrumental chemical analysis is played by electrical methods which measure the basic electric parameters such as voltage and current either directly (e.g. in electrochemical systems) or indirectly after conversion of another kind of signal (light, pressure, etc.) into an electrical signal.

Each measuring device can be divided into three main basic components: (1) the detection device (or input transducer), containing the input transducer (sensor, detector), of the physical or chemical quantity which is to be measured (temperature, concentration); (2) the signal modifier in which modification of the signal take place before its measurement; (3) the output transducer in which the modified signal from the signal modifier is converted back into a physical quantity which can be measured (by meters, recorders, etc.). Most input transducers (ion selective electrodes, polarographic electrodes, photocells, thermistors, etc.) work as analogue devices which continuously indicate the physical properties of the measured system, or

changes in them, by an electrical signal. The output signal from the input transducer is very often not suitable for direct measurement, thus it is frequently necessary to modify this signal or convert it into an electrical quantity suitable for further handling into the output transducer (the measurement of the potential of the high resistance ISE serves as a good example). Moreover with some input transducers, the level of the output signal is very low so that the signal must be amplified before measurement. Also other operations are frequently performed on the input transducer signal. In determining the amount of current passed during a given time, the signal is integrated; in determining the rate of signal change, differentiation with respect to time is performed. In measurement of transmittance it is necessary to obtain the ratio of the signals corresponding to the radiant power transmitted by the system and to the incident radiant power. In absorbance measurements, the logarithm of the ratio of two signals must be found. It is frequently necessary to find the sum or difference of two or more signals. For control purposes, the signals corresponding to the actual and the required states are compared. It is obvious from this brief survey of the basic oparations, which might be supplemented with a number of other operations such as squaring, multiplication or division etc., that various mathematical operations are carried out on the input transducer signal. Even amplification of the signal may be considered to be multiplication of the original signal by a constant greater than unity, or equal to unity in impedance matching. Attenuation of the original signal can, on the other hand, be considered to be multiplication by a constant smaller than unity.

As an ideal signal modifier the operational smplifier (OA) can be considered. With the operational amplifier it is possible to perform, in suitable circuits, various mathematical operations such as addition, subtraction, multiplication, division, integration, differentiation, etc. All these operations are used in the handling of electronic signals, therefore the OA can be used for construction of various partial circuits, a set of which forms the basic circuit of the measuring instrument. Thus with a OA--modular system many types of measuring techniques can be implemented (e.g. for potentiometry, coulometry, polarography, conductometry, spectroscopy, temperature measurement, etc.).

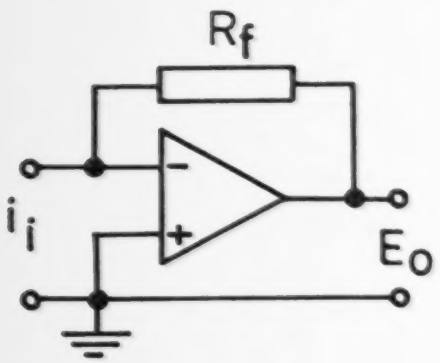
The OA is a low cost electronic component produced in the form of an integrated circuit on a silicon chip. As an electronic construction element the OA can be considered to be a "black box" since its properties are already determined (by the producer) and its function can be varied only by means of external circuits. The worker acquainted with the function of OA is able to construct various measuring instruments himself. Only the function of the apparatus need to be considered and the best way of connecting the OA in the overal circuit in order to obtain an apparatus with the required properties. The OA has thus become the modern building block of electrical measuring devices.

The OA and the fundamental circuits

The operational amplifier is basically a differential amplifier with two input and one output terminals. Other terminals serve for grounding and for connection with the power voltage supply (usually +15V and -15V vs. ground). A signal brought to the negative input leads to an output voltage of the opposite sign (for this reason this input is also called the inverting

input). A positive (negative) signal brought to the positive input causes a positive (negative) signal at the output. If two different signals are brought to the two inputs, the output signal is the difference of the input voltage, multiplied by the gain value (usually 10^5) of the OA. A significant property of the OA is the fact that, at zero input voltage, the output voltage is also zero; another advantage is a high input and a low output impedance.

A vital part of the OA circuit is the feedback loop, by means of which the desired function of the amplifier is "programmed". Through the negative feedback loop a part of the output voltage is fed back to the input terminal. As the negative input is used with the grounded positive input, this output voltage has the opposite sign to the input voltage and is subtracted from it. The negative input is thus maintained by the feedback current very close to zero potential; the negative input can be considered to be a point with a low resistance for any input current signal. If a resistor feedback is used the circuit of a current follower is obtained at



$$E_o = -i_i R_f$$

Fig. 1. Current follower, i_i-input current signal, R_f--feedback resistor, E_o - output voltage.

which the output voltage is a linear function of the input current signal (Fig. 1). From this principal circuit many other OA circuits can be derived (voltage amplifiers, integrators, etc.). If a resistor is connected to the negative input terminal of the current follower - an inverting voltage amplifier is obtained (Fig. 2).

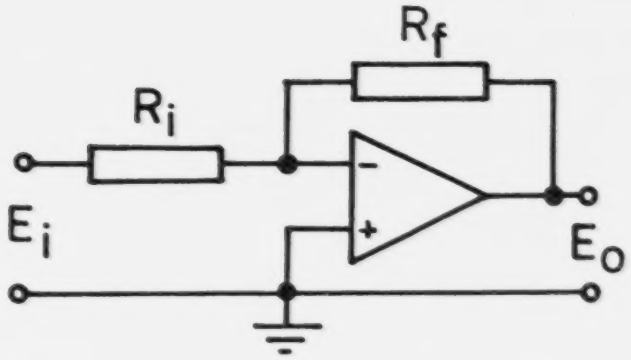
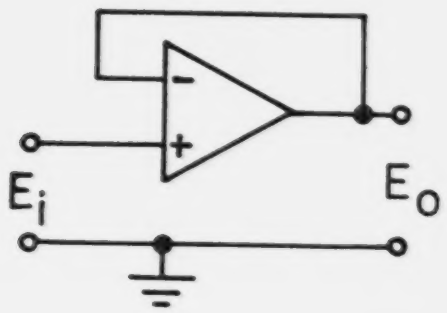


Fig. 2. Inverting voltage amplifier. E_i - input voltage signal, R_i - input resistor, R_f - feedback resistor, E_o - output voltage.

An other very important circuit used in chemistry is the voltage follower. The total output voltage of this amplifiers is fed back to the input by short connection the output terminal with the negative input terminal. The signal is fed to the positive input terminal. This circuit is chiefly used for impedance matching because of its high input impedance (Fig. 3).



$E_o = E_i$

Fig. 3. Voltage follower. E_i - input voltage signal, E_o output voltage.

For electroanalytical devices, circuits in which a capacitor is placed in the feedback, thus providing an integrating circuit, are also very important (amplifier 1 in Fig. 7).

The concept of the modular system with OAs

The use of the OA permits two different construction approaches to be used: either the instrument can be constructed as a single-purpose device or an OA modular system can be employed for assembling the required apparatus. The problems of the latter approach will be discussed below.

The OA modular system contains a chassis, with ± 15V power supply sources for the OAs (but also battery operation is possible), into which modules containing the operational amplifiers are inserted. The amplifier input and output terminals

are placed on the control front panel of the module. Most of the connectors are doubled to facilitate interconnection. A free connector is also placed on the frontpanel, for easy connection of other passive elements into the amplifier circuit. A potentiometer for offset compensation is also placed on the panel. The system can be supplemented by other functional modules, e.g. a reference voltage source a resistor decade box (10 KΩ to 1MΩ), multipliers, analoque switches, sample-hold circuits, conversion modules, etc.

The module with reference voltage sources contains two independent variable sources, controllable from 0 to ± 1.4 V. The appropriate polarity is adjusted by a selector, which connects a dry cell with a voltage divider. The output terminals are doubled to allow measurement of the adjusted voltage by an external voltmeter. The advantage of this arrangement lies in the possibility of using floating sources. The individual modules are then interconnected by cables thus a circuit is constructed in accordance with the scheme of the instrument. Such a system makes construction of the required device substantially faster and allows easy circuit modification during introductory tests of the apparatus. An apparatus of this kind can be very easily supplemented with further circuits, if necessary. After completion of a measurement, the apparatus can be taken apart in a very short time and used for construction of another device. Interconnection of several units is also possible when a complex apparatus is to be constructed.

The OA modular systems are advantageous for school laboratories, which have so far chiefly been equipped with single--purpose instruments. Commercial single-purpose instruments yield the required results, but their function, frequently complicated, is often not understood by the students. With

a modular system the student works with functional units, from which he assembles a particular apparatus himself. In this way teaching can be centred more on basic questions, helping the student to plan a suitable instrumental arrangement for the particular measurement and to grasp its basis, rather than acquainting him with details of the construction of various instruments.

On Fig. 4 is the OA modular system developed in the J. Heyrovský Institute of Physical Chemistry and Electrochemistry of the Czechoslovak Academy of Sciences which is frequently used not only for research purposes in the Institute but also for teaching instrumental analytical chemistry at the Charles University and in the UNESCO courses on analytical chemistry held in Prague. The modular kit contains (from left to right) a modul with $\pm$ 15V voltage source, two sources of variable reference voltage, four modules with a resistor decade (10 KΩ to 1 MΩ) and four modules with OAs. The first one is equipped with a chopper stabilized OA, the others with a FET OA (e.g. integrated

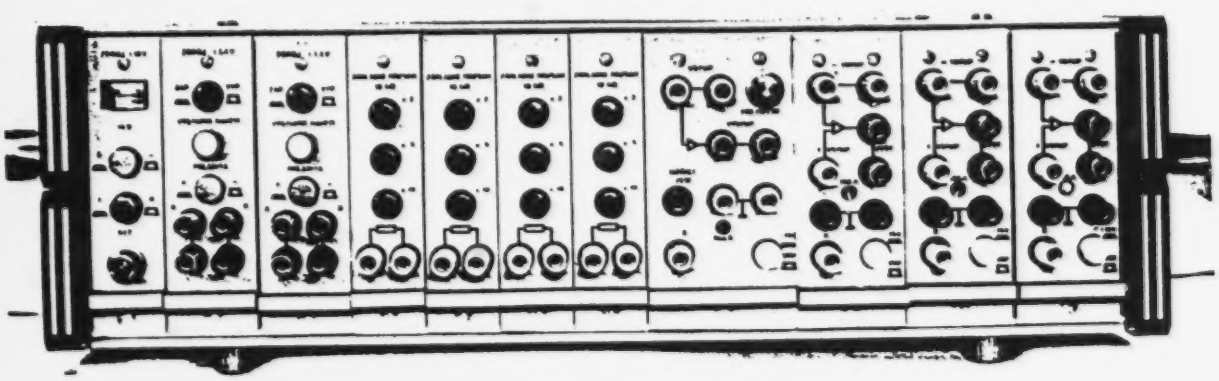


Fig. 4. Modular system with operational amplifiers.

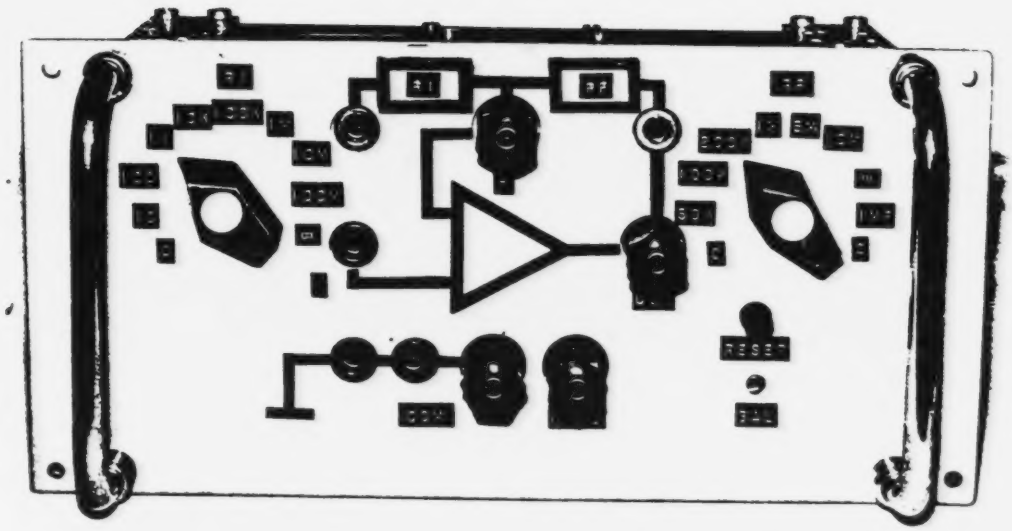


Fig. 5. An OA unit for teaching purposes.

amplifiers of the type CA 3140 in teflon sockets).

A simple system designed mainly for teaching purposes is on Fig. 5. It has two resistor decades from 10 KΩ to 100 MΩ placed on the panel of the OA module, for easy construction of the input and fedback circuits (i.e. adjustment of R_i and R_f values) by simply setting a selector.

Examples of the application of OA in chemical instrumentation

The modular system allows various electrical measurements in chemistry or other fields to be made. On this place only few principal examples are given, more details are given in ref. 1.

Potentiometric measurements

These are basically measurements of the voltage of a cell consisting of a pair of electrodes immersed in a electrolyte solutions. Considering the relatively high internal resistance of the cell, one of the main measuring conditions is that a low current be drawn from the cell, i.e. that the measuring circuit should have a high input resistance. If a measuring error of 0.1% is satisfactory, then the input resistance of the measuring circuit must be at least 1000 times the output resistance of the measured source.

Electrode potential measurement can be performed directly or by the Poggendorf compensation method. An OA can be employed for both; it serves basically as an impedance transducer between the electrode system and the meter itself, which may be a moving--coil meter. For direct measurement, a voltage follower can be used as an impedance transducer, with the indicator electrode connected to its inverting input (Fig. 6). The reference electrode is connected to ground and a meter is connected to the output.

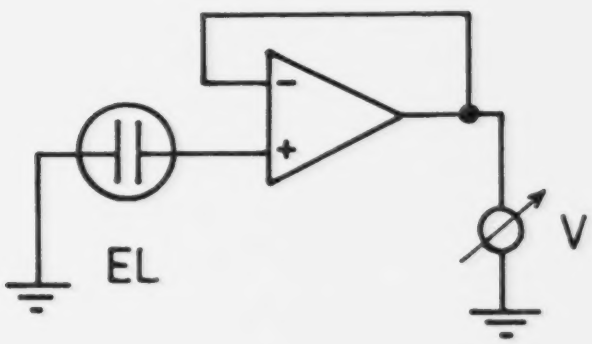


Fig. 6. Voltage follower used for electrode potential measurements. EL - electrode system, V - voltmeter.

Polarographic measurements

The scheme of a simple type of d.c. polarograph is on Fig. 7. This device contains a ramp generator and a current follower. OA 1 is connected as an integrator and suplies a voltage increasing uniformly with time, monitored on voltmeter V. After a preset value has been reached, the charging supply voltage E can be reversed to provide a uniformly decreasing voltage, e.g. for cyclic voltammetry. If the polarizing voltage is to be kept constant, it is sufficient to disconnect the

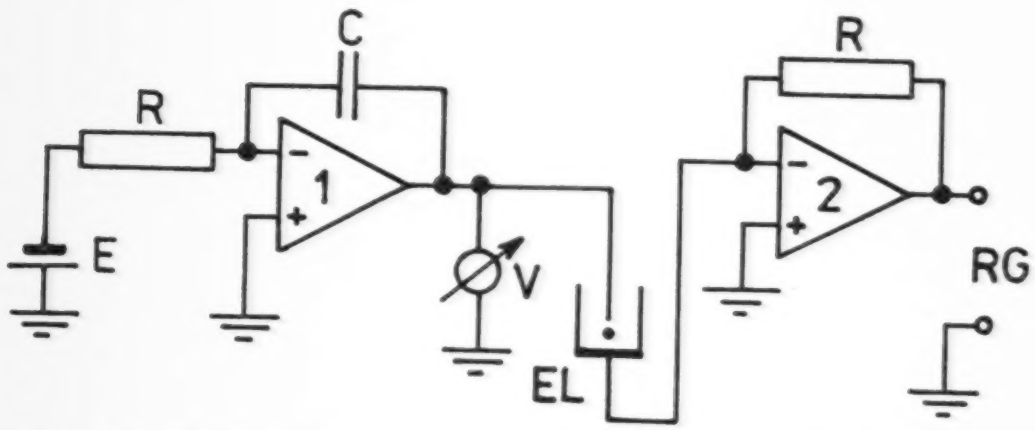


Fig. 7. Scheme of a simple d.c. polarograph. OA 1 and OA 2 - FET operational amplifiers. For description see the text.

input voltage: the integrating capacitor C remains in charged state. Zeroing is provided by short-connecting the capacitor. The working electrode (e.g. a dropping mercury electrode) is connected to the output of OA 1 and the reference electrode to OA 2 wired as current follower, with a recorder (RG) on its output. Damping of oscillations (due the mercury dropping electrode) can be achieved by capacitor (approx 1 μF) connected in parallel to resistor R_f. For amperometric titrations

a simple constant voltage source (e.g. a battery with a 100 Ω potentiomter) and a current follower are sufficient.

Conductance measurements

In conductometric measurements on solutions, the electrodes are connected in a series with a source of a.c. voltage E_i (a OA sine wave oscillator can be used[1]) to the input of an inverting amplifier. For the cell resistance holds the relation

$$E_o = -E_i \frac{R}{R_{EL}} = K \frac{1}{R_{EL}}$$

where R_{EL} represents the resistance of the electrolytic vessel. The arrangement on Fig. 8 can be used also for conductometric titrations.

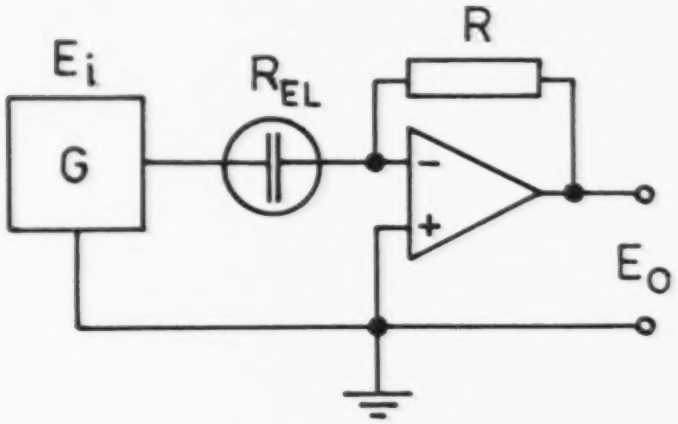


Fig. 8. Circuit for conductometric measurements.
G - sine wave generator yielding voltage E_i,
R - electrode system.

Spectral measurements

In optical measurements OAs are particularly useful for handling signals from the detectors (vacuum phototubes, photodiodes, photomultipliers), and as intensity regulators for the light source.

In measurement of transmittance, the measuring process consists basically of comparing the photocurrents from two phototubes. For this purpose current followers can be used and their output signals compared in a differential amplifier(Fig.9). Voltage source E on Fig. 9 serves for initial zeroing of both photocell signals.

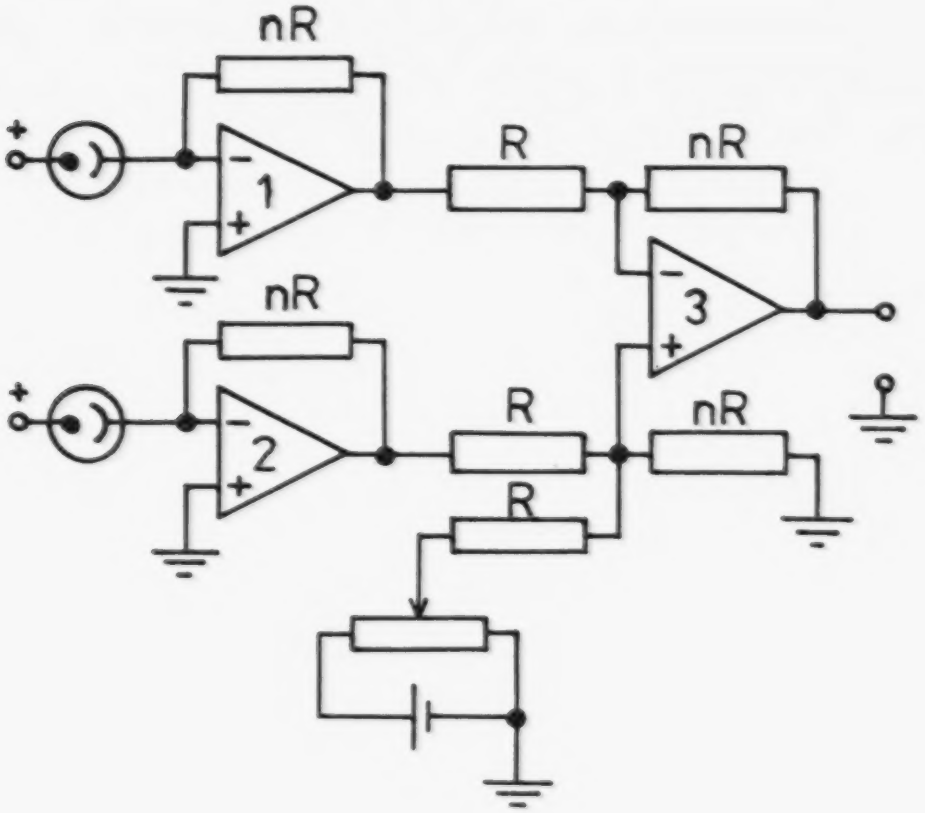


Fig. 9. Circuit for measuring the ratio of signals from two photocells. OA 1 and OA 2 wired as current followers, OA 3 as differential amplifier.

Conclusion

In previous chapter only few examples of the application of OAs in chemical instrumentation are given. Of course many other instruments for measuring electrical and non-electrical quantities in chemistry can be constructed using the modular system.

When designing apparatus, the requirements of the input transducer and the output signal must first be specified, and then the kind of input transducer signal, its level, and the transducer output resistance taken into consideration and the properties of individual elements of the signal-handling apparatus specified. Especially important are the signal modifier input resistance, the kind of analoque function required, the noise and drift level, impedance matching of individual parts of circuits, etc. During the design of any measuring apparatus, the over-all scheme is divided into individual circuits and then these partial circuits are constructed and suitable OAs chosen, so that they have the most convenient parameters for the task required.

Summarizing, this modular concept offers (1) better understanding by students of the principles involved in chemical measurements, (2) creating the possibility of constructing home-made apparatus, (3) allowing the design of instruments for construction in the electronic lab or workshop, and (4) offering low-cost instrumentation for chemical education and laboratory use.

Literature

1) R. Kalvoda: Operational Amplifiers in Chemical Instrumentation. E. Horwood - J. Wiley, Chichester, 1975.

LABORATORY WORK IN THREE UNIVERSITIES IN THAILAND

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In this workshop the emphasis is placed on the provision of low cost equipment, an emphasis which has led to an impressive array of ideas, ranging from the simple and zero cost to the sophisticated but inexpensive. However, laboratory teaching is more than the mere provision of equipment. The availability of the best equipment in the world is no guarantee of a good laboratory course whilst some very successful courses have been run on next to nothing. The way the course is run and the philosophy behind it is very important. It is this aspect which is the subject of the present paper.

In his talk, Dr. P.E. Childs, suggested that it is a general phenomenon, independent of country and educational level, that academic staff

- lack confidence
- lack skills
- lack knowledge
- lack motivation.

He suggested that to bring about a change of attitude on the part of academic staff a catalyst is needed and this catalyst can be provided by appropriate courses.

In this paper I wish to describe one set of courses which has moved some way in the direction indicated by Dr. Childs, a series of workshops on first-year laboratory work at three universities in Thailand. The workshops, held in November/December, 1982 involved the chemistry departments at Chiangmai, Khon Kaen and Prince of Songkla universities. Their first-year laboratory work was reviewed and analysed. At the conclusion of these workshops some members of staff from each department produced outlines of new laboratory activities and their suggestions were the subject of correspondence between themselves and the two UK consultants involved in the programme (Dr. A.G. Harding, Univerity of Bradford and Professor S.F.A. Kettle, University of East Anglia). In July, 1983 another series of three workshops was run in which the development of these laboratory activities was carried a stage further, culminating in their use in a practical laboratory with actual first-year students. This may not sound a particularly exciting sequence but I believe that the outcome was truly remarkable. This outcome was, inevitably, dependent upon the content of the workshops themselves so it is necessary to discuss this aspect in more detail.

The teaching of laboratory skills to first year students is seen as a particular problem in all of the three universities at which workshops were held. It is therefore pertinent to detail the contents of a typical first semester laboratory programme, and this is given below; it is a course covered by chemistry, engineering, medicine, mining, biology, physics, and agriculture students.

Stoichiometry (heat a hydrate)

Molecular weight (CCl_4, O_2)

Close packed solids

Acid-base titrations

Energy and chemical change

Calorimetry

Electron transfer (pH, cells, corrosion)

Oxidation-reduction.

The first set of workshops was based on four principles:

1) One member of the team must be indiginous
2) Individuals must not be exposed (except individual members of the team!)
3) Work must be in the local language as far as possible
4) Common experience should be provided as a basis for the workshop

The indiginous staff came from a fourth Thai university - Chulalongkorn University in Bangkok; Dr. Pirawan Bhanthumnavin and Dr. Somkid Kaewsonthi were the two local members of the team.

What were seen by the local staff as the problems in first year laboratory work? The students, the laboratories and the staff themselves all cause problems:

Students - ill-prepared
poor background
low interest
lack of practical skills
too many.

Laboratories - equipment poor and in short supply
too few staff
poor correspondance with lectures
instruction sheets difficult to follow

Staff - often not interested in the students
often not interested in the experiment
not trained
overworked, underpaid.

Given all of these problems it is pertinent to ask why it is necessary to do laboratory work. Posing this question tended to produce a shocked surprise; some of the reasons suggested by the local staff are given below.

To prove hypotheses and theories
To improve understanding
To teach more chemistry
To improve laboratory skills
It is a course requirement
It works - the system is bad but students learn although not taught

Gives work for staff

Makes graduates employable

To satisfy students' curiosity

To create scientific minds

To stimulate students' interest

After analysing some (rather bad) UK laboratory instruction sheets, some local instruction sheets and participating in a rather unusual laboratory experience, staff suggested a list of what should be seen as ideal aims appropriate to first year laboratory work. These ideal aims came to occupy a central position in the workshop. It is instructive to compare them with the perceived aims of actual laboratory work listed earlier.

Ideal Aims for first year laboratory work

Aim	% importance
To provide motivation for study	25
To provide experience in the scientific method	25
To teach techniques	15
To create self-confidence	10
To reinforce theory	10
To show a relevance of the subject to the real world	10
To give experience working as a member of a team	5

Most of these aims have a subject-independence - a weighting of only about 25% is given to chemistry-specific aims. If these ideal aims were held to be generally applicable then they have very considerable implications for the teaching of chemistry, particularly for non-chemistry specialists - the 'ideal aims' given above were held to be equally applicable to chemistry specialists and non-specialists.

The emphasis on laboratory work as a motivating experience, and as a method of gaining insight into the scientific method, led the staff to completely change the format of some of the normal laboratory work (although the content invariably related to the course content given above).

Some twenty-six pieces of laboratory work were designed; that carrying familiar titles, in fact, contained rather novel ideas. Some of the more eye-catching titles are given below, explanatory comments being added in brackets.

Train and fail. (Volumetric analysis - see below)
Preparation of an aluminium compound from aluminium cans. (Aluminium sulphate).
Determination of iron in soil. (From Khon Kaen University).
Water pollution. (Trace analysis).
How to produce an industrial product in an economic way.
Real of fake? (Is this yellow metal really gold?)
Chemistry and energy.

As indicated earlier, these proposals for new laboratory activities were refined by correspondence with the consultants. The object of the second set of workshops was to develop them to the point at which they were ready for students use. The actual pattern of the workshops differed significantly at the three institutions but was roughly in the following sequence:

Local staff choose activity, nominate those to run the laboratory

↓

Nominees and consultants work on the laboratory activity

↓

Nominees design laboratory activity

↓

Nominees carry out laboratory activity - as students (one consultant acts as instructor, the other observes)

↓

Review design of activity

↓

Modify design of activity

↓

Activity run with real students with nominees as instructors; other staff observe

↓

Review by all staff.

Two examples of the type of activity involved are given below:- In the first a simple twist turns what is normally a rather boring piece of laboratory work - the titration of a strong acid with a strong base - into one in which the students' attention is focused on sources of error and their elimination. Both student interest and performance were found to be enhanced by this change of focus. Comparison with the normal laboratory procedure indicates that in the revision given below a conscious effort has been made to separate training from assessment - a student's performance is not being marked against a secret answer.

Train and Fail:-

a) The instructor demonstrates an acid-base titration - roughly

b) distilled water is added to one solution (so its concentration is known by no-one); then students titrate

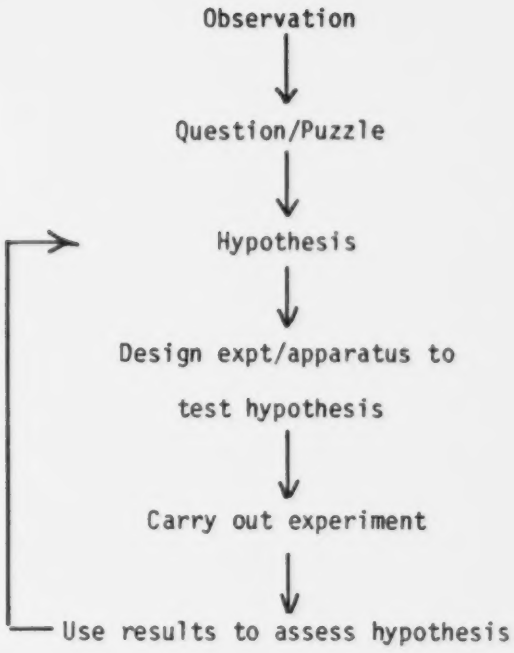
c) students write their titre on a piece of paper which is put into a box. These anonymous titres are written on the black-board by the instructor

d) students discuss the origin of the (evident) errors in small groups; suggestions are collected and remedies asked for by the instructor

e) the concentration of one or more solution is again changed; and the sequence repeated.

When the class is showing adequate skill, the students measure relative acidities of e.g. Coke, Fanta, 7-Up etc.

The above piece of laboratory work led to considerable improvement in student motivation. Work based on the scientific method was also found to be motivating. It is sometimes held that because first-year students are not yet trained they are incapable of participating in laboratory work based on the scientific method, but this overlooks the fact that the "scientific method" is widely used in everyday situations - for example when a door obstinately refuses to shut or a bucket, filled with water, is later found to be empty. The pattern of "scientific enquiry" which is appropriate in such situations is:-



In this sequence the academic in charge of the laboratory exercises control by choosing the area of observations that the students make, although the actual observations themselves may include things which were not expected. The students, in groups, compare their observations and list the questions/puzzles which their observations raise. Next they can be asked to suggest possible ideas or rationalisations which might explain their observations. Many suggestions are likely to be offered and it is necessary to bring the class together to produce a generally accepted hypothesis. At this point the staff member can exert some control over the direction of the subsequent work. Breaking into groups again, students can be asked to design an experiment/apparatus with which to test the hypothesis (it is quite a good idea to get them to look at each others work and to ask them to suggest improvements). The staff member has the task of bringing these designs to a unity (perhaps by providing an apparatus actually available in the laboratory) and

leading the class to decide just what experiments need to be carried out. Because the whole class is working together a large number of variables can be tested simultaneously; each student's measurement can be duplicated if this is felt desirable. Because the group are working as a class there is less pressure on individuals - an error in one measurement is unlikely to unduly affect the overall conclusions. The final stage - that of drawing the class results together and the discussion of the lessons to be learned from them - is one at which the staff can involve themselves in very effective teaching. Because the pattern of experiments chosen and results obtained may not be entirely predictable, the staff member must have thought through in advance the possible outcomes. Clearly, in this pattern there need be almost no written instruction for the students but there certainly is a need for good guidance for the staff. It seems sensible to maintain a file on each experiment so that each staff member can each year contribute his own experience to help staff responsible for the activity in the following year.

Two examples of this approach follow. In the first a comparison is made of the reaction between granulated zinc and zinc dust with HCl. Here students commented on (a) the different rates of reaction, (b) the different amounts of heat liberated, (c) the different smell of the gas coming off.

Observation

Granulated Zn + HCl - compared with Zn dust + HCl

Question

Why does the Zn dust/HCl get hot?

Hypothesis

Heat liberated depends on the extent of reaction

Design

An apparatus to measure the heat liberated as the extent of reaction is varied

Experiment

As a class, with the provided apparatus, covering a range of variables (acid concentration, total volume, quantity of zinc dust)

Results

The outcome was that the hypothesis made quantitative and more experiments suggested

At a different university, a group of engineers were provided with an aqueous solution of sodium chloride made acid with HCl. They were told that this was a sample of water taken from a nearby tidal river and asked to make observations on the corrosion of metals in it. The task was presented as a problem:-

A steel bridge in the (tidal) water has recently become subject to chemical effluent and is corroding badly. A sample of the water is provided. Make recommendations about how the corrosion can be reduced.

As a record of the laboratory session they were asked to write a one-page report.

Observation

a steel nail and galvanized iron in the water + $K_3Fe(CN)_6$ solution as indicator

Question

why does the steel nail, but not the galvanized iron, corrode?

Hypothesis

corrosion of the iron depends on the metals it contacts as well as the composition of the solution.

Design experiment

different metals + iron in saline solutions (different concentrations, different pH's)

Carry out experiment

the class covered the variables of metals, concentration and pH

The results were used to assess hypothesis and provide a basis for the individual one-page reports.

One important aspect of this novel type of laboratory work lies in the role of the academic staff

In the new type of laboratory work staff no longer act as laboratory instructors but rather as laboratory managers.

- what tasks to set individual students
- what tasks to set groups
- how to receive and handle student/group responses
- when to stop one phase of the activity and move to the next
- it is usually better to respond to questions with questions rather than with answers
- they have to decide how to maintain control and to dictate general direction.

As the next stage of the work the three Universities are planning to incorporate some of this new type of activity into their laboratory programme.

They are also planning to produce a book, for general circulation within Thailand, in which experiments developed along these lines are explored. If this compendium of workable ideas proves valuable perhaps a wider circulation could be envisaged.

CHEMISTRY FOR DEVELOPMENT

J. V. Kingston, Division of Scientific Research and Higher Education, Unesco

There is a universal agreement that the amelioration of the life of populations of the Third World countries - the developing countries - is both an awesome task and the responsibility of all mankind.

How can chemists and chemistry help in this endeavour? How can we effectively direct chemistry for development? It is well to remember that chemistry and the chemical industries are one of the means by which the value of natural resources are improved. Chemistry has also made major contributions to other sectors - particularly health, agriculture and energy. Although chemistry is of major importance to the economics of the rich northern countries, it has played a far less significant role in the poorer countries of the south. While there is an urgent need now for these countries to strengthen and improve their chemical and allied industries, this must be done through a process of endogenous development - development which suits the countries and their populations rather than trying to emulate the activities of the industrialized countries.

Unesco is committed to the development of endogenous capabilities in science and technology and has consistantly endeavoured to support and develop programmes for developing countries.

In this talk I would like to describe the Unesco programmes in chemistry and speak in some detail about the International Organization for Chemical Sciences in Development (IOCD) - an organization created by Unesco specifically geared to Chemistry for Development.

The principal objective of the Unesco programmes in the chemical sciences is to promote the development of chemistry in our member states - its effective teaching in their schools and the university, the pursuit of research, both

fundamental and applied, and the applications of chemistry to human welfare and to production. The principal approach we take in this support of chemistry is to encourage international cooperation among teachers of chemistry, research specialists and government and industrial leaders, believing that this cooperation can bring about a wider exchange of information, lead to joint planning of cooperative research projects in critical areas of need and enhance the competence and relevance of the individual scientist and teacher. In organizing this international cooperation we depend on the scientists themselves, acting through their professional organizations at national, regional and world-wide levels, to advise us and to obtain the commitment from their governments and institutitions required in implementation of this cooperation.

Unesco is especially mindful of the glaring inequalities in resources and effort in the basic sciences that mark our world today; fully 95% of all scientific research is carried out in the industrialized antions - most of it on matters that concern these nations and their economies - leaving a mere 5% distributed through the vast majority of nations we term the developing countries. Our response to this imbalance is to have a strong commitment to building up an endogenous capacity in science in the developing countries. This finds us encouraging all aspects of this build-up: training of specialists, provision of material resources and assistance in institution-building at the local and regional levels.

Unesco support to the training of specialists in chemistry is extensive. In fact most of our programmes have been centred around training, ranging from programmes of formal education to a variety of training courses.

In all of our activities we have continually borne in mind the importance of national professional societies and have, wherever possible, tried to help and strengthen such societies. However, in many countries, the

small number of working chemists has inhibited the growth of such societies, so Unesco has encouraged the formation of regional groupings; an example of this is the Federation of Asian Chemical Societies. The regions in fact are very large - Latin America and Africa being two of them - and we attempted to provide possibilities for regional co-operation in areas which were of genuine interest to local chemists through the establishment of regional networks.

These cooperative activities don't just come into being. They have a relatively long lead time and part of their success, or lack of it, rests on the labours of local people, both in helping with the organization of the programmes and with setting out long-term objectives which can help chemists and chemistry in their countries and their region.

Presently there is in each region at least an embryonic activity, most of which are referred to as networks of collaborating institutions. All are independent in that they are guided by either a board, constituted from members from the region, or by the regional chemical federations. Each is, to some degree or other, given back-up support by the relevant Unesco regional office for science and technology and by our chemistry programme. The long term aim of Unesco is that these regional groupings will become independent, both in the management and funding of their programmes.

The formation of the IOCD in 1981 thus came about not simply because of the recent recognition on our part of the importance of chemistry and chemists in technological development. Unesco has long recognised this and its programme, past and present, bears testament to this importance. Rather, the establishment of IOCD occurred because of the realization that there was still a missing element. We now believe this element to be the continuing, not just ad hoc, involvement of influential chemists in the guiding and implementation of Unesco's programme in the chemical sciences.

The IOCD is seen as the means to this end. The involvement we seek is of a kind that will secure a commitment to Unesco, beyond giving advice, to enablement, embracing wherever possible or necessary institutional support and financial sustenance. We would hope that through the good offices of the IOCD, awareness of the Unesco programme and its objectives will become as pervasive as chemistry itself and continue to attract widespread support.

IOCD sought from its beginning, in 1981, to concentrate on those multi-disciplinary areas where chemistry can make a major contribution and where research could and would be carried out in developing countries. Thus it is seeking to develop programmes which are mission-oriented in the following areas - health, energy and food as well as education and training.

The first research programme relates to the synthesis of anti-parasitic agents - compounds which would be active against certain tropical diseases - the "poor man's diseases." This project now involves eleven laboratories in developing countries, where the compounds are being synthesized. IOCD is providing all back-up services, including physico-chemical measurements, information services and research advisors. These services are now available to all research workers in developing countries and will soon be expanded to include equipment maintenance. A second programme in the field of human fertility is being designed and we hope it will be operational shortly.

These examples are indications of the way we wish to proceed - using IOCD to consolidate Unesco programmes in chemistry as they relate to development and providing a link between the various programmes and services.

In the field of education and training Unesco has had a long experience and has had the fullest support of IUPAC in framing and implementing programmes. The present project on locally-produced teaching equipment stems from a joint

IUPAC/UNESCO endeavour in university laboratory teaching. This programme has been regional in character and five regional laboratory workshops have resulted in the publication of five volumes of Sourcebooks of Chemical Experiments in four languages - Arabic, English, French and Spanish. The experiments themselves have been devised and tested by local university teachers who have written them up in a way in which they would wish to present them to their students.

In building upon these two activities we have been developing in IOCD a programme related to university/industry interactions which could be implemented through regional networks. Believing that good analytical chemistry will provide the basis for so much of the work of chemists in developing countries, we are proposing a prototype field-oriented analytical chemistry undergraduate course and then broaden this into a regional programme, including technician training, rudimentary equipment maintenance and then add in the present programme on locally-produced equipment.

In all our proposals related to university teaching and training we have emphasized that undergraduate training must reflect the actual milieu, within which the graduate chemist is expected to work and for what purpose.

Chemistry has an active role to play in the socio-economic development of the third world. Unesco and IOCD are determined to help direct the efforts of chemists towards the solution of these problems. However, without the help and goodwill of chemists in institutions in both developing countries and industrialized countries the programmes on chemistry for development will have no impact.

CHEMICAL REACTION AS A RANDOM PROCESS - A MONTE CARLO SIMULATION

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Objectives

1. To simulate a first order reaction.
2. To apply the first order rate equation to the data obtained to obtain analogues of:

a. the concentration/time curve.

b. the semilogarithmic concentration/time plot and the "rate constant".

c. the rate constant from the initial slope of the "rate" curve.

3. To use a standard procedure for fitting a straight line to scattered linear data.

Materials required

A 10x10 numbered grid and 100 small counters.

A table of random numbers or decimal dice or a pack of cards.

Log. tables and graph paper.

Procedure

1. Each grid square represents one molecule or atom of reactant.
2. Starting anywhere in the table of random numbers work along a line or down a column covering up the numbers in the grid as they occur. Keep a record of:

   I = the number of random numbers taken from the table.

   N_I = the number of grid positions <u>not</u> covered at each value of I.

   For I = 1 - 10 each event should be recorded. For I = 11 - n it is only necessary to record the results after each 5-10 random numbers used. Tabulate: I N_I and $\ln N_I$.

Calculations

1. The rate at which the grid is covered is given by:

$$(a) \quad -dN_I/dI = kN_I$$

Plot N_I (y-axis) against I (x-axis).

2. In order to determine k equation (a) is integrated to give:

$$\ln N_o/N_I = kI$$

This can be rearranged to give:

$$\ln N_I = \ln N_o - kI$$

$$\text{i.e.} \quad y = a - bx$$

Plot $\ln N_I$ against I and use one of the methods given on a separate sheet to obtain the best straight line an "k" for the process.

3. In this particular process it is easy to obtain data during the early stages of the process and "k" may be determined from the initial slope $-dN_I/dI$ of the "concentration" / "time" curve which is usually linear over the first 10-20 % of a reaction.

Determine "k" from the initial slope by plotting, on a larger scale, the data for I=0-10. How does this value compare with that obtained from the semi-log plot?

Further work

How could you adapt this method to study the analogue of the equilibrium

$$A \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} B$$

If you can devise a method try it out and see if it works in practise.

Ref. Rabinovitch, J. Chem. Ed. 46 (1969) 262.

00	01	02	03	04	05	06	07	08	09
10	11	12	13	14	15	16	17	18	19
20	21	22	23	24	25	26	27	28	29
30	31	32	33	34	35	36	37	38	39
40	41	42	43	44	45	46	47	48	49
50	51	52	53	54	55	56	57	58	59
60	61	62	63	64	65	66	67	68	69
70	71	72	73	74	75	76	77	78	79
80	81	82	83	84	85	86	87	88	89
90	91	92	93	94	95	96	97	98	99

A water dipping model for first order kinetics

Objectives

1. To carry out a macro-simulation of the first order process.
2. To use the data from the simulation to determine a rate constant from a plot of the first order rate equation.
3. To determine the units of the first order rate constant by dimensional analysis of the rate equation.

Materials

Square section juice or milk carton.

Trough aproximately 20x20x7 cm.

Measuring cylinder 100 or 250 cm^3.

Graph paper.

Procedure

1. Pour water into the trough to a convenient height but do not allow the depth of the water to exceed the height of the dipper when it is lying on its side. Measure the volume of the water = $^{A}V_{o}$.
2. Place the dipper flat on its side on the bottom of the trough. When the water is still, rotate the dipper to the upright position using the rear edge as a hinge. Do not use a scooping action or create ripples as this leads to poor results.
3. Use the measuring cylinder to measure the amount of water in the dipper. Record this reading = x cm^3. Discard the water in the dipper.
4. Repeat steps 1,2 and 3 until no more water can be removed from the trough.
6. Record the data as follows:

   D = the number of dips.

   x = volume / dip.

   $^{B}V_{D}$= cumulative volume i.e. $x_1 + x_2 + x_3 +$ etc.

   $^{A}V_{o}$= initial volume

   $^{A}V_{D} = {}^{A}V_{o} - V_{D}$

7. Repeat the experiment using a different initial volume.

8. Plot the following graphs:

   a. ${}^{B}V_{D}$ vs. D

   b. $({}^{A}V_{o} - {}^{B}V_{D})$ vs. D

   c. $\ln({}^{A}V_{o} - {}^{B}V_{D})$ vs. D i.e. $\ln {}^{A}V_{D}$ vs. D

9. From the graph find the "rate constant" for the "reaction".

Comment

The general rate equation is of the form $-dc/dt = kc^{n}$ where c is the concentration and n the order of the reaction. In this experiment concentration is represented by volume and time by the number of dips therefore for a first order process:

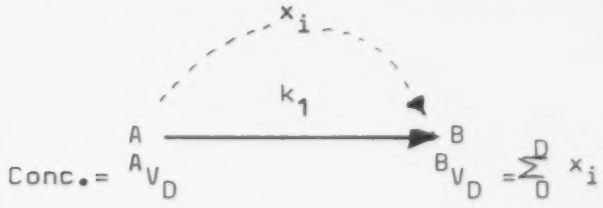
$$-dV/dD = kV$$

$$-dV/V = kdD$$

on integration this gives:

$$kD = \ln {}^{A}V_{o} - \ln {}^{A}V_{D} = \ln {}^{A}V_{o}/{}^{A}V_{D}$$

If possible carry out this experiment with two dippers of different volumes so that you have dippers available of two different "k"s to do more advanced kinetic investigations.



Ref. Birk, Gunter, J.Chem.Ed. 54 (1977) 557.

A study of an equilibrium process

Objectives

1. To determine the equilibrium constant for a process.
2. To show that the equilibrium constant is the ratio of the rate constants for the forward and reverse reactions.
3. To confirm that the rate constant for the process is the sum of the rate constants for the forward and reverse reactions.

Materials

2 Dippers	Measuring cylinder
2 Troughs	Graph paper

Procedure

1. Use two dippers of different, known "k"s and two troughs A and B.

Follow the same procedure as in the previous experiment except that the water is dipped from the two troughs simoultaneously or dipped from each trough before any of the water is transferred.

3. Plot ${}^{A}V_{D}$ and ${}^{B}V_{D}$ vs. D.
4. It can be shown that:

$$\ln(V_o - V_\infty)/(V_D - V_\infty) = (k_f + k_r)$$

hence a plot of $\ln(V_D - V_\infty)$ vs. D gives a value for $(k_f + k_r)$. Does this value agree with the sum of the individual "k"s?

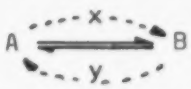
Case 1

At D_o $\quad {}^{A}V_o$

At D $\quad {}^{A}V_o - x \qquad x$

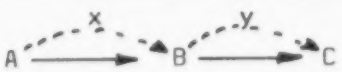
$${}^{A}V = {}^{A}V_o - \sum x \quad ; \quad {}^{B}V = \sum x$$

Case 2



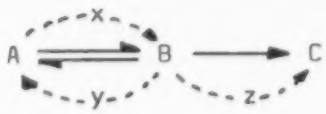
$${}^{A}V = {}^{A}V_o - \sum x + \sum y \quad ; \quad {}^{B}V = {}^{B}V_o + \sum x - \sum y$$

Case 3



$${}^{A}V = {}^{A}V_o - x \quad ; \quad {}^{B}V = {}^{B}V_o + x - y \quad ; \quad {}^{C}V = {}^{C}V_o + y$$

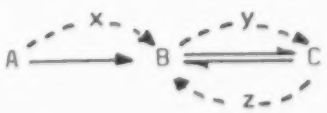
Case 4



Michaelis - Menten enzyme kinetics.

$${}^{A}V = {}^{A}V_o - \sum x + \sum y \quad ; \quad {}^{B}V = {}^{B}V_o + \sum x - \sum z - \sum z \quad ; \quad {}^{C}V = {}^{C}V_o + \sum y$$

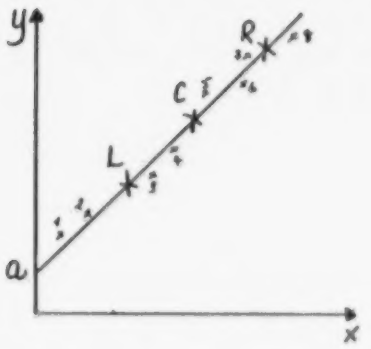
Case 5



$${}^{A}V = {}^{A}V_o - \sum x \quad ; \quad {}^{B}V = {}^{B}V_o + \sum x - \sum z \quad ; \quad {}^{C}V = {}^{C}V_o + \sum y - \sum z$$

Finding the best straight line (simple methods).

1) Three point method



$y = a + bx$

Centroid

C $\frac{1}{8}\sum_{1}^{8} y = \bar{y}$, $\frac{1}{8}\sum_{1}^{8} x = \bar{x}$

L $\frac{1}{4}\sum_{1}^{4} y = \bar{y}_L$, $\frac{1}{4}\sum_{5}^{8} x = \bar{x}_L$

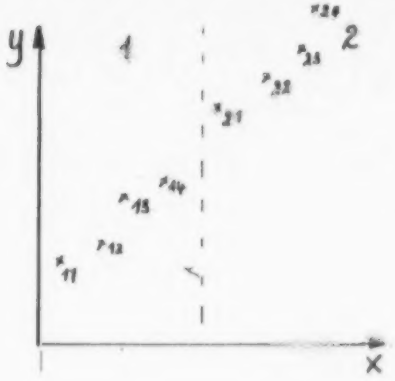
R $\frac{1}{4}\sum_{1}^{4} y = \bar{y}_R$, $\frac{1}{4}\sum_{5}^{8} x = \bar{x}_R$

$$\text{Slope } b = \frac{\bar{y}_L - \bar{y}_R}{\bar{x}_L - \bar{x}_R}$$

$$a = \bar{y} - b\bar{x}$$

---

2) Points in pairs method



$y = a + bx$

$y_{11} - y_{21} = \Delta y_1$, $x_{11} - x_{21} = \Delta x_1$

$y_{12} - y_{22} = \Delta y_2$,

$y_{13} - y_{23} = \Delta y_3$,

$y_{14} - y_{24} = \Delta y_4$, etc.

$$4\boxed{\sum \Delta y} \qquad \overline{\Delta x}$$

$\overline{\Delta y}$

$$\text{Slope } b = \overline{\Delta y} / \overline{\Delta x}$$

Line passes through $\bar{y} = \Sigma y/n$, $\bar{x} = \Sigma x/n$

$$a = \bar{y} - b\bar{x}$$

$$b = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2} \quad , \quad a = \bar{y} - b\bar{x}$$

More accurate than methods (1) and (2) but takes longer. The accuracy of the data may not justify least squares treatment.

A simulation of the rate of a chemical reaction

Required: about 50 each of two differently coloured small objects which are inditinguishable by touch e.g. beads, etc.
A cloth or paper bag; smallcontainers for the objects.

Method

1. Count out about 50 each of the coloured objects and mix them in the bag.

2. Decide on which colour you will collect and begin taking the pieces out of the bag one at a time. Record each selection as it is made keeping the chosen coloured pieces as they emerge but returning the rest to the bag.

3. Record the data as follows:

	Number of dips into the bag = D	Number of chosen pieces collected = C
e.g.	22	10
	23	10
	24	10
	25	11
	26	11
	27	12
	etc.	etc.

4. When you have recovered nearly all of the chosen pieces plot the data as graph of D against C with D as the horizontal axis. This will produce and exponential or "die away" curve.

The effect of starting with different amounts of starting pieces can be studied by varying the starting ratios although the total number should not fall below about 80 and the number of chosen coloured pieces should not be much more than half the total.

You will find that there will be much variation between runs with the same starting numbers. This is a consequence of the method which will only work well with very large numbers, however if you

combine the results of a number of experiments and average the numbers for selected values of D you will obtain nice smooth curves. These can then be compared with one another.

The method can be extended to other systems and of course the integrated rate equations can be used as well but this experiment is particularly useful as an introduction to the ideas of rates at an early stage in the school even before any chemistry has been mentioned and introduces the exponential curve quite painlessly. The results can be compared with exponential curves obtained in other ways e.g. Newton's cooling curve. With younger children using small sweets such as Tic-Tacs or Smarties adds interest to the experiment as they can be eaten at the end.

The rate of decomposition of a chemical compound

Required: White vinegar

Photographer's hypo - solution containig 10-20 g dm^{-3}

Water, liquid measure, glass or clear plastic reaction vessel e.g. small beaker or glass jam-jar etc.

This experiment demonstrates that reactions, in this case a decomposition, take time to occur. During the experiment which indicates that a certain amo nt of one of the reaction products has been formed. By doing the experiment with different amounts of starting material and measuring the time for the same amount of product to form it is found that the time depends on the amount of material there to start with. This relationship can then be shown graphically. By selecting a suitable starting concentration with a reasonable reaction time and repeating the experiment at that concentration but different temperatures it is possible to demon= strate roughly the effect of temperature on the rate of reaction.

Method

1. Using the vinegar and the hypo solution run expt.1. as follows:

a. Measure out 15 cm^3 of vinegar and 30 cm^3 of hypo solution separately.

b. Place the reaction vessel on or in front of a suitable mark, a pencilled cross on a piece of paper will do nicely, so that the mark can be seen through the reaction mixture when it is in the vessel.

c. Mix the two solutions in the reaction vessel and start timing from that point. Record the time when the cross disappears behind the cloudy solution.

d. Carry out five experiments according to the following table:

Vinegar	Hypo	Water
15 cm^3	30 cm^3	0 cm^3
15	24	6
15	18	12
15	12	18
15	6	24

If you have enough time and solutions you can use intermediate values of the hypo solution as long as the total volume of hypo remains 30 cm^3. The time for the reaction can be made to fall into a reasonable range by adjusting the conditions of the experiment so that the depth of the mixed reaction lies between 3-6 cm.

e. When all the times have been measured plot a graph of time vs. volume of the hypo solution with time as the horizontal axis. This should give you the classic "die away" curve characteristic of many reactions and other natural processes, the cooling of a cup of tea for example.

Supplementary experiment

Pick a reaction mixture which gives a reasonable reaction time say between 2 and 6 minutes and before mixing raise the temperature of the two solutions to about five degrees above room temperature (thermometer). You should try both raising and lowering the reaction temperature by five degree steps.

With care you should be able to show that a rise in temperature of 10^o approximately halves the reaction time and vice-versa. This of course has interesting consequences in the cooking of food and the overwintering of plants and animals.

If you would like to convert the "die away" curve into a straight plot $1/cm^3$hypo against time or 1/time against cm^3hypo. This has important theoretical implications but alsoit is of great practical importance. Why?

By running the experiment at different temperatures the effect of temperature on the rate of reaction can be shown by the differences in the graphs of the data.

Note: $\text{Rate} \propto \frac{\text{a change of concentration}}{\text{change in time}} \propto$ starting concentration.

i.e. $\frac{C_{start} - C_{finish}}{t_{start} - t_{finish}} \propto C_{start}$. $k\, C_{start}$ (k is a constant).

$\therefore$ 1/reaction time . k x starting volume of hypo.

or 1/starting volume of hypo . k x time for reaction.

Simulated condensation polymerization

Linear condensation polymers are produced by the reaction of difunctional molecules. If A and B represent the reactive groups of molecules which can undergo a condensation polymerization a difunctional molecule may be one of the following: a) A-A or B-B b) A-B.

With $-NH_2$ & -COOH the product is a polyamide (eg Nylon), with -OH & -COOH the product is a polyester (eg Terylene,Mylar).

Cross-linked polymers are formed in condensation reactions between molecules when at least some of them have a functionality of three or more. Examples of such systems are:

c) A(A)(A) B(B)(B) d) A—A B—B e) A(A)(A) A—A B—B

In industry cross linking reactions may take place during the manufacture of polymers which are then stable to heat and cannot be made to flow or melt; these are called thermosetting resins, one example of which is Bakelite. Most linear polymers however soften when heated and are termed thermoplastic.(Polyethylene, for example).

Polymers may be classified in terms of their molecular weights which are generally indicative of the physical properties which the material posseses. Many of the useful properties of polymers depend critically on their relative molecular "size" therefore a value for the molecular weight is a very useful piece of data. In fact the numerical value for the molecular weight depends on the way in which it is measured and these different values reflect alternative views of the molecular shape and size.

In a polymer sample chains containing different numbers of repeating units are present and it is therefore to measure only average molecular weights.

Methods of molecular weight determination using colligative properties e.g. membrane osmometry, effectively count the number

of moles of solute per unit weight of sample and yield a quantity known as the number average molecular weight = $\overline{M}_n$.

Consider a polymer sample containing molecules of varying chain length each corresponding to a different degree of polymerization i. If the numbers of groups if identical chain length N_i (and hence identical molecular weight M_i) could be counted an average molecular weight $\overline{M}_n$ could be calculated from the average numbers of molecules present of a given chain length. This can be expressed mathematically as:

$$\overline{M}n_n = \sum_1 N_i M_i / \sum_1 N_i = \frac{N_1M_1+N_2M_2+ \text{---} N_iM_i \text{--}}{N_1+N_2+\text{-----}N_i \text{--}}$$

where N_i = number of molecules with degree of polymerization(DP) = i.

M_i = molecular weight of molecules with DP=i.

DP = degree of polymerization = $\frac{\text{No. of molecules of monomer orig.}}{\text{No. of molecules of monomer final.}}$

When a method involving the scattering of light is used to measure the molecular weight the quantity obatained is the weight average molecular weight = $\overline{M}_w$. In this case the chains containing equal numbers of repeating units are"weighed" and an average molecular weight is calculated from the average of the weights of each different polymer chain length present in the sample. This can be expressed as:

$$\overline{M}_w = \sum_1 w_i M_i / \sum_1 w_i = \frac{w_1M_1+w_2M_2+ \text{---}w_iM_i \text{--}}{w_1+w_2+ \text{---} w_i \text{--}}$$

where w_i = the total weight of all the molecules of DP = i.

The ratio $\overline{M}_w/\overline{M}_n$ is a measure of the polydispersity of the system which is a measure of the "spread" of species of varying molecular weight in the system. A synthetic polymer can generally be regarded as a mixture of species which are chemically identical but which differ in chain length. Because of this heterogeneity of chain length the polymer is said to be polydisperse with respect to molecular weight. Any value above unity indicates a spread of species of varying molecular weight. Conversely a value of exactly one means

that the values for the number and weight average molecular weights are equal i.e. $\overline{M}_w = \overline{M}_n$ the "true" molecular weight. Such a system is termed monodisperse and contains species of a single chain length and therefore a single molecular weight. Monodisperse polymers are normally only found as natural products whose synthesis is determined by a unique series of steps which is always repeated to yield the identical product.

For the purposes of this exercise we shall assume that the repeating unit has a constant molecular weight, m, and think in terms of average chain lengths rather than average molecular weights. This is not a drawback since the two quantities are directly related by the proportionality factor m.

Thus the average chain length is:

$$\overline{P}_n = \sum_1 iN_i / \sum_1 N_i \qquad \text{and } \overline{M}_n = m\overline{P}_n$$

Similarly the weight average chain length is:

$$\overline{P}_w = \sum_1 iw_i / \sum_1 w_i \qquad \text{and } \overline{M}_w = m\overline{P}_w$$

where w_i = weight of chains of length i.

The ratio $\overline{P}_w / \overline{P}_n$ is known as the dispersion factor.

The principal characteristics of linear polymerization condensation are: 1) The chains grow slowly so that very high conversions are necessary to produce high molecular weights. The value of $\overline{P}_n$ may be calculated from

$$\overline{P}_n = N_o/N = 1/(1-p)$$

where N_o = the initial number of molecules.

N = the number of molecules at time = t.

p = the extent of reaction (or degree of conversion) at time = t.

When the degree of conversion is 90% (p=0.9) $\overline{P}_n$ = 10 and when it is 100% the polymer chain will be, in theory, infinitely long a condition never achieved in practice.

2) The distribution of chain lengths becomes broader as p increases from 0 to 1.

Here we are considering the assembly of a chain containing difunctional monomers. Polymer chains are assembled in the same fashion when tri- and other multifunctional monomers are present but with one important difference: branching can now take place and this will lead to cross linking of the chains. "Infinite" molecular weight will be attained before the system reaches 100% conversion. The actual degree of conversion reached is known as the critical conversion for gelation p_c and the point of maximum conversion as the gel point. The approach of the gel point is charaterized by lower values of $\overline{M}_n$ and larger values of $\overline{M}_w$ and the onset of a separation of the system into two fractions, a sol or soluble fraction and a gel or insoluble fraction.

In an ideal reaction where p_c is greater than p which in turn greater than zero ($p_c > p > 0$) only intermolecular linking would occur. If $p_c < p < 1$ only intramolecular linking with the formation of cross links would be expected. This is not so in practice as some cross linking takes place before p_c as the value of p approaches this critical point.

Carothers states that for equal numbers of A and B:

$$p_c = \frac{2}{f} - \frac{1}{f\overline{P}_n}$$

where f = the functionality of the system
= the average number of functional groups per monomer molecule.

But, when $p = p_c$, P_n tends to infinity so that the second term may be ignored. For type (c) systems f = 3 and $p_c = 2/f = 2/3 = 66.7\%$.

In the case of systems of type (d) and(e) the value of the functionality will depend on the ratio of di- and tri-functional molecules present.

Example: Product.

Stoichiometric coefficients:	2	3
Mole fractions:	2/5	3/5

Functionality(f) = (f of monomer 1 x mole fraction) + (f of monomer 2 x mole fraction)

= 3 x 2/5 + 2 x 3/5 = 1.2 + 1.2 = 2.4

Hence: $p_c = 2/f = 2/2.4 = 0.833$ i.e. 83.3% conversion.

Ref. Dyson Educ. Chem. 1980, 17, 43.

Simulated condensation polymerization

Materials

100 cell grid

Table of random numbers or random number generator e.g. pack of cards.

Rules

1. Start at any point in the random number table and work through the table from that number in any direction.
2. Each number taken represents a cell (molecule) in the grid.
3. As each random number is taken a line is drawn from the corres= ponding cell in the grid either horizontally or vertically to the nearest available neighbour with the highest number.
4. Availability: a. No difunctional molecule may have more than two lines drawn to or from it.

   b. No trifunctional molecule may have more than three lines drawn to or from it.

   c. There must be no closed loops.

Let $\overline{P}_n$ = average chain length.

n_i = the number of molecules of length i at time t.

p = degree of conversion at time t.

Then: $\overline{P}_n = in_i/n_i = 1/(1-p)$

For a linear condensation at any time t:

1. Count the number of molecules n_i of length i.
2. Find the number of molecules n_i.
3. Calculate $\overline{P}_n$ and p.
4. Tabulate the values of i and n and plot i vs. n_i for different values of p up to 0.9.
5. Plot $\overline{P}_n$ against p.

What are you able to deduce about the course of linear condensation polymerization from your results?

MOLECULAR MODELS FOR (ALMOST) NOTHING

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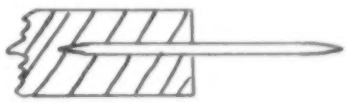
For the teaching of chemistry models are indispensible. Molecuar model sets are expensive. Fortunately, for many purposes it is not essential to have very accurate models; indeed the use of accurate space filling models may hopelessly confuse the student. Since great accuracy is not of prime importance in the early stages of molecular modelling crude, but perfectly adequate, models can be constructed by the student from readily available materials at practically no expense.

Since most elementary stereochemistry is approached via organic molecules the most pressing need is for a large number of tetrahedra which can be easily and quickly linked to form molecules and which can be freely rotated with respect to one another about the bond axes.These are very easily made from corrugated cardboard obtainable from the empty boxes to be found in every shop or supermarket: the owner is usually only too happy to get rid of them. To make the product a little more elegant the cardboard may be painted with a water based emulsion paint (both sides at once to avoid distorsion on drying) before any cutting is done. The cardboard is then marked out with a template (Fig. 1.) and the pieces are cut out with a sharp knife and a metal straight edge. Scissors are not suitable for cutting as they compress the corrugations and make loose fitting joints. It is convenient to make a knifeblade as shown in Fig.2. from a piece of an old hacksaw blade and mount it in a handle. This shape is convenient

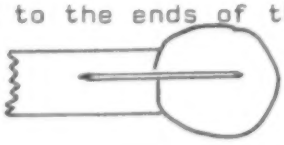
as it can be used for cutting the notch afterwards. The notch is 1 cm deep and as wide as the thickness of the cardboard and the two pieces fit together as shown in Fig.3. Note the direction of the corrugations.

The bonds are made by inserting double pointed cocktail sticks into the ends of the arms thus:



These form surprisingly stable connectors.

With these units chains and rings can be constructed and free rotation and conformational differences can be demonstrated. To demonstrate configurational differences additional coloured units can be attached to the ends of the arms thus:



While these models are adequate for many purposes they suffer from the drawback of not indicating the relative sizes of atoms or groups of atoms and the volumes which they occupy. This can be overcome to some extent by using scaled silhouettes. A convenient size has a scale of 2" (2.5 cm) = 1Å (100 pm) and the pieces are cut with the aid of templates made using the table of covalent and van der Waals radii given below.

Atom	r_{cov}	r_{vdW}	Atom	r_{cov}	r_{vdW}
H-	0.3	1.2	N=	0.53	1.5
C-	0.77	1.7	N≡	0.39	1.5
C=	0.67	1.7	S	1.04	1.85
C≡	0.60	1.7	F-	0.64	1.35
O	0.66	1.4	Cl-	0.99	1.80
O=	0.46	1.4	Br-	1.14	1.95
N-	0.70	1.5	I-	2.15	1.33

Aromatic ring or π- bond thickness 3.2.

Special templates for C=C, C=O, and CONH can also be made Figs. 4,5,6 which extend the range of these models considerably.

The use of these models may be further extended by the use of other units made according to the appropriate v.d.Waals and covalent radii to simulate the space filling charachter of the atoms which slot together as shown in Fig. 7.

π- bonds can be represented quite well by using cotton wool sprayed with hair-holding spray, artists fixative or diluted gum solution, attached to cocktail sticks.

The two dimensional silhouettes alone serve a useful purpose since they can be used to demonstrate, for example, the relative sizes of atoms e.g. the halogens or the size changes which occur when the alkali metals are ionized.

One final example of a cheap but perfectly adequate model is that of the α-helix the template for which is give in Fig. 8.

These units may be rapidly cut out of file card or other light card and fitted together quickly to demonstrate the extended polypeptide chain or, by linking through the hydrogen bonds, a very stable helical structure.

The use of card, paper or corrugated carboard for making cheap and useful models has been briefly illustrated here but the range of both static and dynamic models which can be made is limited only by the ingenuity of the maker. Some of the other possibilities will be described in the educational literature at a later date.

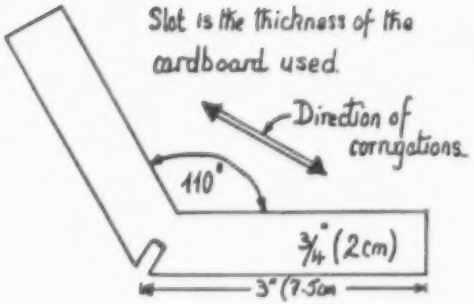


Fig. 1.

Fig. 2.

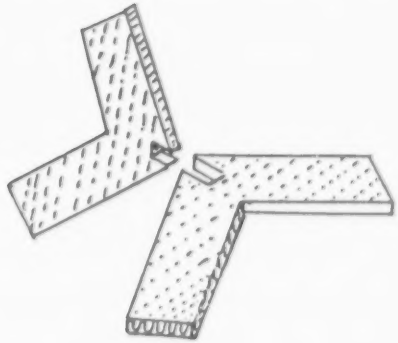


Fig. 3.

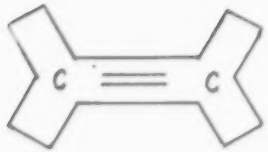


Fig. 4.

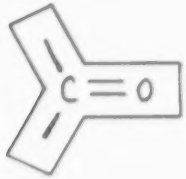


Fig. 5.

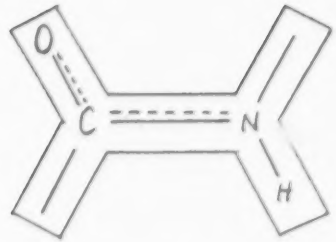


Fig. 6.

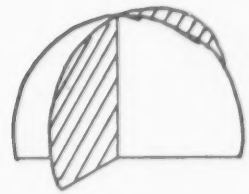


Fig. 7.

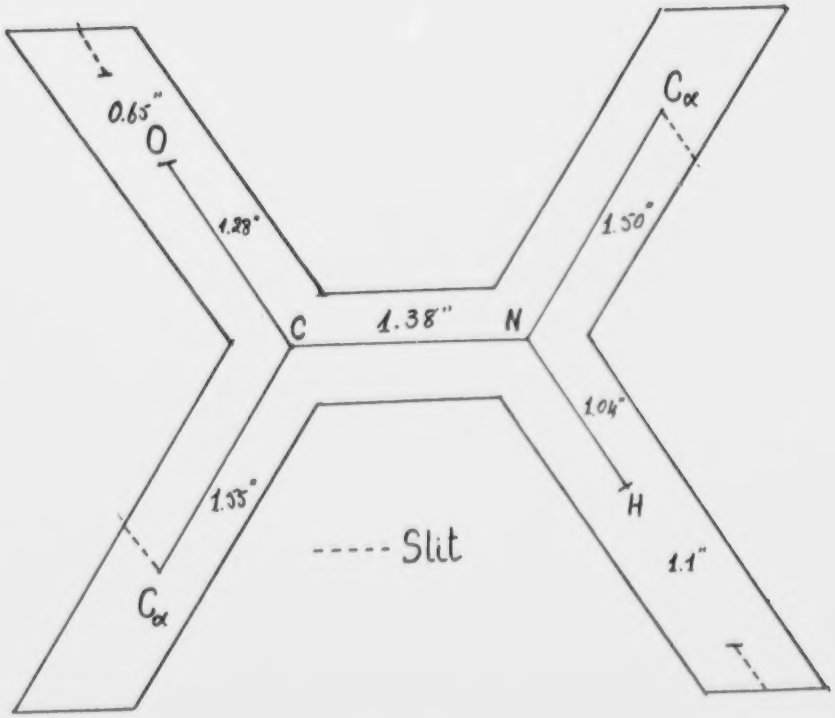


Fig. 8.

SIMULATIONS FOR TEACHING ELEMENTARY KINETICS

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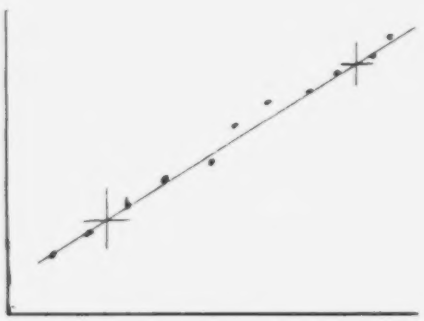
Students beginning the study of kinetics are likely to have difficulties in two areas 1)mathematics 2) chemistry. From a teachers point of view it is helpful to separate the two and give the student a chance to see the mathematics in action without having to worry about the chemistry and this is possible by means of simulations with physical processes or mathematical models. Nowadays it is more and more the ca e that games and simulations are implemented on a microcomputer (how one does get caught up in the jargon!). If, however, like me you have no microcomputer, then it is necessary to fall back on simpler (and cheaper) methods which, if slower, are equally instructive and have the added advantage of being readily adaptable to ones own needs without the need to write new programmes or, even worse, buy new programmes.

The experiments which follow are not, on the whole, original but have been adapted from similar experiments in the Chemical Education literature. The important thing is that they work, students enjoy them, and they require very little in the way of equipment and materials to set up. In addition the simulations are all capable of being expanded to deal with quite complex kinetics to illustrate reaction mechanisms and enzyme kinetics of the Michaeli-Menten type.

Also included are some simple methods for finding the best straight line which are of sufficient accuracy for most student experiments and save all the tiresome work involved in a least squares treatment. An additional, very quick method which is suitable for large numbers of points which are not too scattered is as follows and is taken from Rapid Statistical Calculations by M.H.Quenouille (2nd Ed., Charles Griffin & Co., London):

1) Using vertical lines, divide the N observations into three roughly equal groups.
2) Find the median points for the first and third groups.
3) Join the median point to get the regression line. If there is a large scatter a better estimate is obtained by drawing a parallel line through the median point $(\bar{x},\bar{y})$ or one third nearer the overall median point.



Diag. 1.

With the ready availability of calculators it seems appropriate to give another very useful method which, though tedious, is very adaptable and can be used with a simple four funtion calculator. If a programmable calculator or micro-computer is available more complex cases can be dealt with.

The method is illustrated for a simple first order reaction $A \xrightarrow{k_1} P$ for which we can write:

$$-\frac{dA}{dt} = k_1 A \simeq -\frac{\Delta A}{\Delta t}$$

which gives $A = -k_1 \Delta t\, A$

let $k_1 \Delta t = k'$ $\quad A = k'A$

Using this relationship we can calculate a value of A from some initial concentration A_i. This value then serves as the new A_i for the next calculation.

i.e. $A_{i+1} = A_i - k' A_i \qquad k' \leq 0.2$

This operation is repeated n times and the tabulated values of A_{i+1} and n are used to construct the appropriate graphs from which k' and k_1 can be calculated for given values of t.

This method can be applied to more complex systems in an analogous manner. The method has been described in a more complicated manner by Miller (Educ. in Chem. 1972,9,222) and by Formosinho and Miguel (J. Chem. Ed. 1979,56,582).

USING TRADITIONAL MATERIALS FOR EQUIPMENT IN CHEMISTRY EDUCATION - NEGLECTED RELATIONSHIPS WITH THE SUBSTANCE OF NATURE

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I would like to thank Erik Thulstrup for the opportunity of introducing to you a simple apparatus and a few second thoughts.

Let us start with the practical side. The apparatus is a distillation device made of clay, a pot still, as it is used in Africa, e.g. in Kenya, to distil a local liquor, called chang'aa, from sugar-cane beer. The apparatus has been built by a potter in Kiel following a sketch in a Chemistry Reader from the School Science Project for East Africa. The title of the reader is Fermentation and Distillation (Ingle, 1975). We have used the still for a school project on the preparation of aromatic oils from plants (Minssen and Nentwig, 1983; Minssen, 1983).

So, instead of exporting an idea or an instrument from a Western Country to Southern or Oriental Countries we learned from there without the intention of re-exportation.

The pot still consists of four parts, which are fitted into each other. The main part is the big distillation jar, ornamented by imprinting Kauri shells into the clay, when it was still soft. The ornamentation is an essential feature. The jar contains as a second part a strainer or a sieve, which in turn supports a small crucible, the third part, which is to

receive the distillate. Fourth and finally, a bowl, filled with water, makes up the top and acts as a condensor (see photograph). When leaving the crucible out, you can use the

pot - still for extractions with water, for instance for extraction of water soluble dyes from plants. The extraction resembles the known Soxhlet procedure.

The pot-still can be used outdoors more easily than the usual glassware laboratory equipment for steam distillation which requires an even level to have the separate units of 2 distillation flasks, one condenser and one receiving flask in a row. Though a steam distillation is more efficient with some

respects, it was important for us to be able to do a piece of natural science outside instead of dealing with the matter of nature indoors. I would like to remind you of early French perfume distillery where the farmers had transportable copper stills which they carried to the fields to distil the fresh lavender harvest.

This leads us to the second thoughts on working with traditional materials such as for instance clay. One key word I would like to borrow from Bill Robertshawe from Stockholm: Working Milieu or Working Environment. As a second category I introduce: Neglected Relationships with Matter.

When I went to this workshop on Locally-Produced Laboratory Equipment I expected to see equipment made partially from local materials like different woods, stoneware, copper, brass, or even straw and leather, maybe also calabashes, some of them ornamented, in addition to standard laboratory vessels. Instead of local materials I found locally available materials. What is the difference? One of the frequent questions of the workshop was: "What do you do when you are out in the bush and want to do science and have no equipment? - You reach out and take the things which are around you: These are thrown away cola tins, burnt out light bulbs and neon tubes, emptied out plastic dishwasher bottles, used up plastic syringes." This omnipresence of western waste I find disturbing though I was impressed by the versatile inventiveness to use these things, to teach the scientific basis to generate eventually more of those materials in addition to perhaps more precious products. So plastic-made urine bags could be used for volumetric measurements to teach gas laws or as oxygen supplies for welding devices to construct thermoelements. Some of the low cost materials employed are especially useful since they are unbreakable and

inflatable. Still, they are not only low cost but cheap in the sense of being ugly. This would not be intolerable if the materials mentioned would just add in a practical way to the traditional ones. But, I am afraid, they not only replace traditional materials, they drive them out.

But what is so ugly about plastics and what is beautiful with traditional material? This is hard to define. Let us take a local example. To me Copenhagen is a green city not only on account of trees and lawns alone but also on account of the copper helmets and copper roofs which have developed patina in the course of decades and centuries. Nobody would want to substitute them by plastic tiles even if these would be cheaper and more durable. As the famous architect Paul Bonatz has put it: patina is the breath of god which disdains plastic. Likewise, traditional materials, similiar to natural objects, can develop an individual history which is unique in each case and shows on their surface. No piece of rock resembles its neighbor, in the grain of a piece of wood fat and lean years are preserved. In contrast, anonymity prevails in the chemistry laboratory. Matter, as object of investigation and material of equipment, purified white powders, colorless liquids on one hand, and glass, plastic, stainless steel, aluminum on the other hand have to be or are standardized and stripped of an individual history at the cost of uniqueness and specialty. So, whereas chemistry and its working environment provides insight into molecular structures of matter it neglects essential components of natural or traditional objects as individuals shaped by age. As a parallel it neglects, on the side of the human subject, half of the personality, the unconscious part, which might want to have satisfying relationships and feel at home with his or her material surroundings, with building materials, materials of laboratory vessels and with matter in general.

So: matter does matter, and it is not without meaning whether we use mostly brass and copper or aluminum, clay porcelain and wood, or plastic, whether we allow ourselves the luxury of ornaments or restrict ourselves to unadorned function.

As you have seen, this modest clay jar is filled with some troubled thought. I wonder, whether in a not too distant future, it might be conceivable to combine the requirements of modern laboratory equipment with the use of traditional materials and traditional ornamenting, still preserved within the skills of some local artisans, workshops or even factories.

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A LOW-COST AND LOW-RISK CRACKING EXPERIMENT

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Descriptions of simple small scale cracking experiments are rather common in textbooks and laboratory manuals for the secondary level.

This paper is concerned about the safe handling of rather large amounts of crack gas in an apparatus which consists of low-cost standard components.

The produced amount and "quality" of crack gas allow several qualitative as well as quantitative investigations to be carried out.

Cracking of paraffin oil (bp 250-350°C)

Instruction:

1. A test tube is filled with "catalyst pearls" (of the aluminium silicate type often used in industry). Heat the pearls in a Bunsen flame until all absorbed water has been boiled off.

2. Pour about 3-5 ml liquid paraffin into another test tube (Pyrex or the like). Add so much glass wool that the wool is able to absorb the paraffin oil. Pour the dry catalyst pearls on the top. The test tube is now

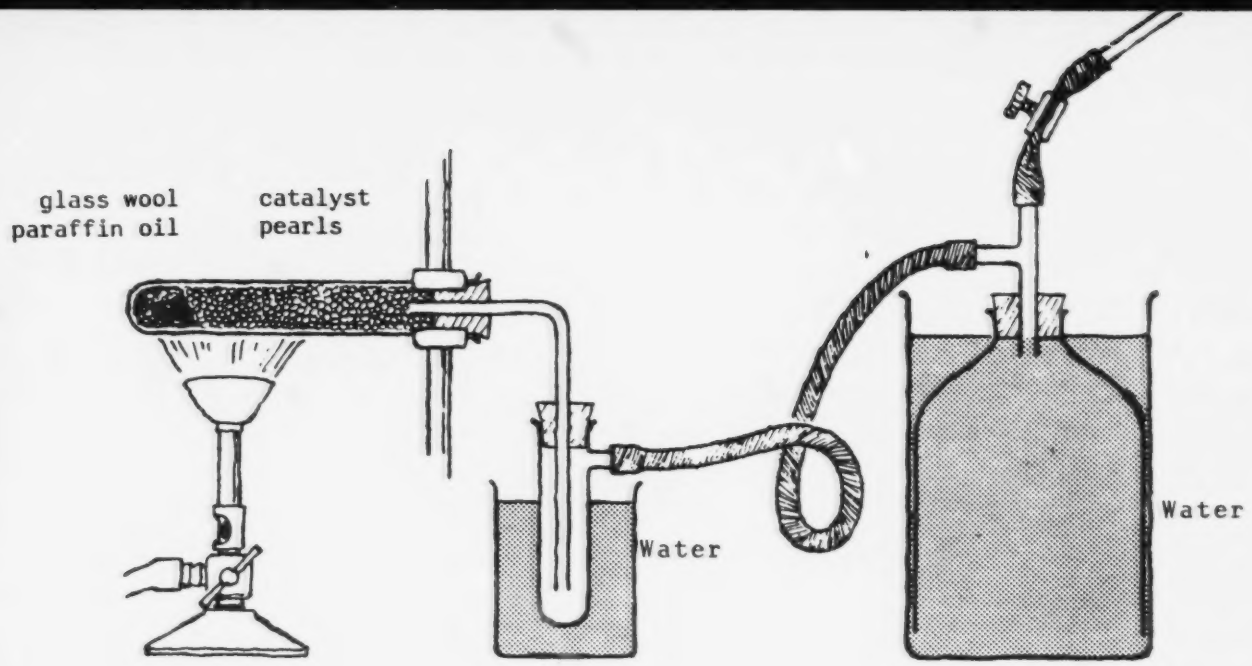

Fig. 1. Apparatus for the cracking of paraffin oil.

mounted with the apparatus as shown in Fig. 1. The performer has to wear protecting goggles.

3. Heat the catalyst pearls intensively for a couple of minutes. Now move the burner a little in order to heat the paraffin oil too. Hereby the liquid paraffin flows slowly into the warm catalyst where the cracking takes place. Gradually a liquid is condensed in the water cooled filter tube. In the gas container a gas is collected. To avoid any air contamination, you have to let out the first 50 ml of gas which have been formed.

Notes about the cracking experiment

The inner volume of the apparatus is rather small compared with the gas volume formed. This is an important safety factor. Break of the test tube will result in smooth burning of the flowing gas without any risk of explosion as the air contamination of the crack gas is negligible. Low air content is also important if further quantitative investigations are to be carried on.

The gas container consists of a polyethene or PVC bottle of low weight, with the bottom cut off. It is of course important to ensure total water filling of the bottle before start.

The gas container can be replaced by a urine bag according to principles discussed in another paper of this report.

The physical and chemical behavior of the liquid condensed can be investigated by standard procedures (boiling point interval, test for double bonds, etc.).

Investigations of the crack gas

Crack gas is a mixture of alkanes, alkenes, and hydrogen. The gas has a characteristic "alkene smell". It burns with a yellow soothing flame. But if the gas mixture before lighting is passed slowly through a glass tube with a little platinum activated charcoal, two important observations can be made. The flame is now less lighting and less soothing, and the gas tube with the platinum catalyst becomes hot due to the reaction between the alkenes and hydrogen

$$R\text{-}CH{=}CH_2 + H_2 \rightarrow R\text{-}CH_2\text{-}CH_3$$

A quantitative determination of the alkane alkene hydrogen volume porportions can be carried out in the apparatus shown in Fig. 2. It consists in the "low-cost version" of two plast syringes (50 ml) (and in the "high-cost version" of two glass syringes (100 ml)). In the glass tube is placed a little platinum activated charcoal between two wads of glass wool. The threeway stopcock can be omitted or replaced by a T-shaped glass tube and some sort of tubing clamp to close the system.

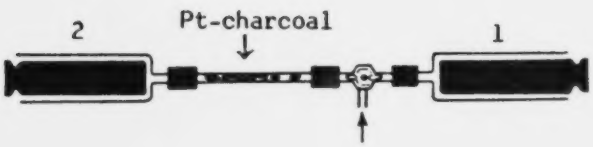

Fig. 2. Plast syringe apparatus for the quantitative analysis of crack gas.

Procedure

A:
Flush the plast syringe apparatus with a small amount of crack gas to remove the air. Fill syringe No. 1 with 50 ml of crack gas and close the system. Pass the crack gas slowly through the catalyst until constant volume is obtained. A decrease in volume ($-\Delta V_a$) is observed.

B:
Fill syringe No. 1 with 50 ml of crack gas and syringe No. 2 with for instance 20 ml of hydrogen. Close the system and pass the gas mixture slowly through the catalyst until constant volume is obtained. If $-\Delta V_a = -\Delta V_b$ one more experiment has to be done.

C:
Fill syringe No. 1 with 50 ml of crack gas and syringe No. 2 with for instance 20 ml of a pure alkene (ethene or 1-butene). Close the system and pass the gass mixture slowly through the catalyst until constant volume is obtained. The decrease in volume $-\Delta V_c$ is observed.

Typical syringe readings are listed below:

$-\Delta V_a = 15$ ml

$-\Delta V_b = 23$ ml

$-\Delta V_c = 15$ ml

From these data we can evaluate the composition of the crack gas in volume %.

alkene	46 %
hydrogen	30 %
alkane	24 %

Reasonable results are obtained with plast syringes if the piston is well lubricated. A simple glass tube manometer inserted in the measuring system can improve the accuracy of the measurements.

A LOW-COST "NITRIC ACID PLANT" AND OTHER EXPERIMENTS USING THE URINE BAG TECHNIQUE

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The handling of gases and gas mixtures in lecture experiments often demands rather complex equipment. The urine bag technique discussed in this paper makes it possible to improve many standard experiments from several points of view. First of all this technique can reduce the complexity of the experiment which in itself is of pedagogical value. Transparent PVC urine bags are available in most countries at low prices from medical suppliers. They represent an important safety factor in the handling of toxic, inflammable or even explosive gases or gas mixtures.

The nitric acid plant

As a first example we shall look at a very simple experiment in which a nearly stoichiometric mixture of ammonia and oxygen is burnt into nitrogen dioxide. Oxygen and ammonia are prepared by standard methods (Fig. 1) and the gases are col-

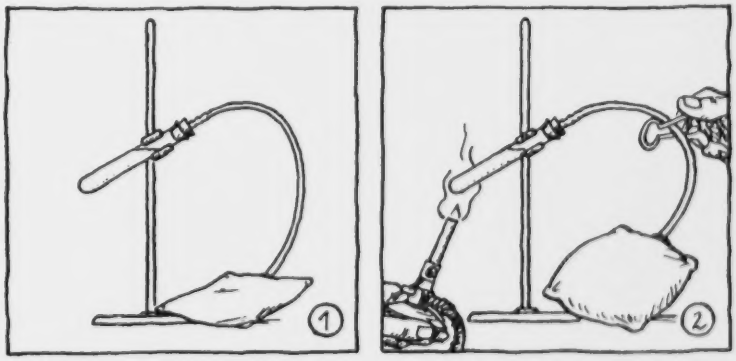

Fig. 1. NH_3 gas prepared from a solid mixture of NH_4Cl and $Ca(OH)_2$.

lected in urine bags. One urine bag of ammonia and two urine bags of oxygen are connected, and the content of the system is mixed by squeezing the bags in turn for a short time.

The nitric acid plant consists as shown in Fig. 2 of a small glass tube with a wad of platinum asbestos (10 %) acting as a catalyst in the middle fixed by a filling of pumice on each side. One urine bag filled with the 1:2 NH_3/O_2 mixture is connected to the glass tube - and we are ready to go!

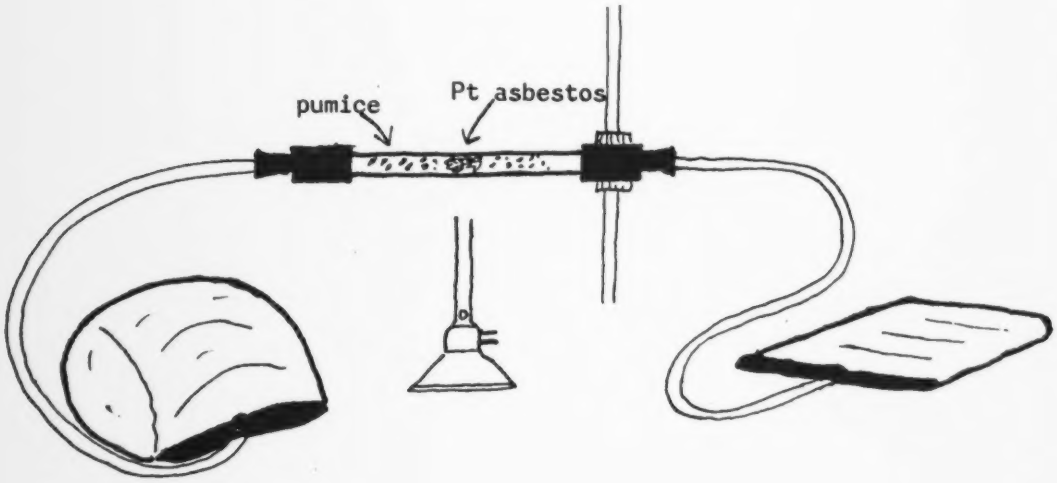

Fig.2. A "nitric acid plant". A mixture of NH_3 and oxygen is slowly passed over hot Pt asbestos.

Heat the catalyst and press carefully the gas mixture through the tube. Remove the burner and observe that the heat of reaction keeps the glass tube glowing. In the urine bag on the other side of the tube a red gas mixture is collected. The volume proportions observed reflect the following reactions:

(a) $4\ NH_{3(g)} + 7\ O_{2(g)} \rightarrow 4\ NO_{2(g)} + 6\ H_2O_{(l)}$

(b) $2\ NO_{2(g)} \rightleftarrows N_2O_{4(g)}$

By cooling the urine bag in ice water the colour almost disappears, and a significant reduction of volume is simultaneously observed. By heating the urine bag in hot water we observe instead an increase in colour intensity and gas volume. The large temperature effect on volume and colour intensity is important in discussing the equilibrium reaction (b).

In order to obtain nitric acid a little amount of water is poured into the urine bag. This can be done as shown in Fig. 3 which prevents gas escape to the surroundings.

Fig. 3. How to mix gas and water!

By shaking the urine bag the gas is absorbed in water according to the reaction scheme

$$(c) \quad 3\ NO_{2(g)} + H_2O_{(l)} \rightarrow 2\ HNO_{3(l)} + NO_{(g)}$$

The volume of NO actually observed from reaction (c) depends on the original volume proportions in the NH_3/O_2 mixture. With oxygen in excess almost no NO is formed of course.

A mixture of NH_3 and O_2 is explosive above app. 900°C. The pumice in the glass tube is cooled by the flowing NH_3/O_2 gas mixture and prevents a chain reaction to pass back into the urine bag. For safety reasons we only have to shield the glass tube.

Perspectives of the urine bag technique

To give an idea of the wide application range of the urine bag technique a few additional examples shall be discussed briefly.

The reaction between hydrogen chloride and water

This reaction is usually demonstrated in the well-known fountain experiment. In the "urine bag alternative" a little water is added to a urine bag filled with HCl gas (Fig. 3). The urine bag will collapse, and very hot hydrochloric acid is formed. The temperature obtained in the solution depends of course on the amount of water added.

Preparation of pure NO gas

When nitrogen oxide is prepared by standard methods at school it is always contaminated with nitrogen dioxide. Contaminated NO collected in a urine bag can be washed by adding a little amount of water (or NaOH solution) (Fig. 3). Shake the bag for a few seconds and you have almost pure NO gas which can be pressed into another empty and dry urine bag. An empty urine bag contains almost no air apart from the small air volume in the plast tubing. To avoid air contamination it is only necessary to flush an empty urine bag with a very small volume of the gas. If you perform the reaction of NO and O_2 by connecting two urine bags of NO with one urine bag of O_2 you feel the heat of reaction and you

observe colour change and the decrease of volume according to the reaction schemes (d)

(d)
$$2\ NO + O_2 \rightarrow 2\ NO_2$$
$$NO_2 \rightleftarrows 2\ NO_2$$

The reaction between ammonia and hydrogen chloride

The proton transfer reaction between ammonia and hydrogen chloride can be demonstrated by mixing equal volumes of the two gases as shown on Fig. 4. You have to be very

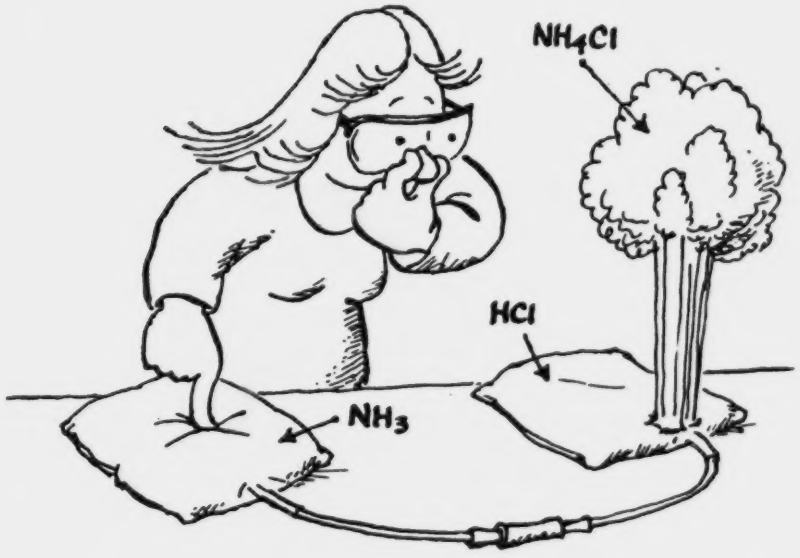

Fig. 4. More care next time!

careful, indeed, to avoid melting down the urine bags. But if you succeed, you end up with two urine bags filled with solid ammonium chloride and almost zero gas volume.

Many other gas reactions can be studied in a similar way, for example the reaction between H_2S and SO_2 - the so-

called "Claus reaction" well known from oil refineries. Here the gases are mixed in the volume proportion 2:1, and you end up after some time with three flat urine bags containing moist sulphur powder.

A mixture of hydrogen and chlorine

A 1:1 mixture of hydrogen and chlorine is an explosive mixture. The reaction initiated by light (from an ordinary flash bulp) is usually demonstrated in glass apparatus. The urine bag technique represents a striking and high safety alternative as shown in Fig. 5 where the teacher has been involved a little too much (in order to show the acid formed on a piece of indicator paper).

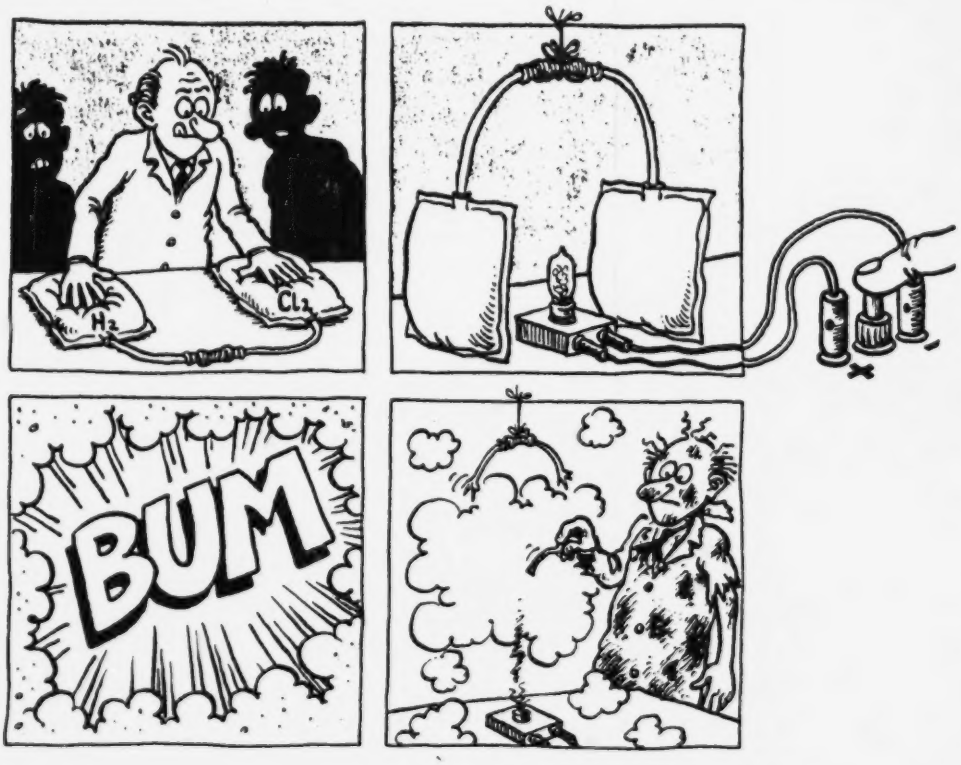

Fig.5. The reaction between hydrogen and chlorine initiated by flash light.

Most of the examples cited here are of course teacher demonstration experiments as highly toxic gases are involved. In pupils' laboratory work with gases urine bags are also of great value. In experiments with oxygen and carbon dioxide for example, the teacher can deliver to each team a urine bag filled with gas (from a cylinder). Do not spend so much time preparing gases that no time is left for using them!

Urine bags are in Denmark used in two sizes, 0,7 litre and 1,4 litre max. gas volume respectively. Some qualities have a "valve" which can be wrapped off before use. The price in Denmark is equivalent to 0.05 $ - 0.10 $ each dependent on the number of bags.

The standard urine bag is suitable for most gases used in school laboratories.They are not completely gastight, but for short time use this represents a minor problem. (Chlorine and some organic gases, for instance freon 11, tend to diffuse more quickly through the PVC wall than many other gases as a result of specific chemical and physical interactions with the polymer wall.

Another paper in this report by J.J. Christiansen is concerned with determination of gas volume in urine bags.

Examples of urine bag technique in Danish school books

L. Engels and P. Norrild, Hverdagslivets kemi, 2nd ed. Gyldendal, Copenhagen, 1983 (Textbook+Teacher's Manual)

L. Engels and P. Norrild, Stoffer i hverdagen, Gyldendal, Copenhagen, 1981 (Textbook + Teacher's Manual)

P. Norrild, Superfos A/S Fredericia, DR, Copenhagen, 1981

IN BRAZIL FIA IS ALREADY A ROUTINE TOOL

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Flow Injection Analysis (FIA) is often regarded as a new, somewhat academic approach which still has to make its inroad into analytical praxis. Therefore, naturally, frequently the question is being asked whether FIA is practical to be applied for routine assay of a large number of samples. There is, however, one laboratory where the answer to what FIA offers has already been rendered. Perhaps, unexpectedly, this laboratory is situated in a town named Piracicaba (250,000 inhabitants), in the state of Saô Paulo, Brazil (Fig. 1).

The laboratory is part of the Centro de Energia Nuclear na Agricultura (CENA), which is a specialized research institute of the University of Saô Paulo. Piracicaba is situated in the centre of a region which traditionally has extensive agricultural production (primarily sugar cane, but also coffee, corn, citrus fruits, cotton and beans), which in turn forms the basis for a number of industries related to these crops (sugar plants, distilleries, etc.). This is from where approximately 50% of the samples come while the other half originates from many CENA activities (plant breeding, soil fertility and chemistry, animal science, and environmental

Fig. 1. Brazil, the 5th largest country in the world.

projects related e.g. to the Amazon region). It is one of the specific conditions of a developing country that many of these samples have to be transported more than 3,500 km to a laboratory with sufficient expertise and instrumentation, but as CENA is by and large the only laboratory of its kind in Brazil, this is the only feasible solution. Taking this into account it is understandable that the analytical laboratory was forced to make as many as 300,000 determinations last year, on materials as diverse as those shown in Table I.

FIA is one of the two main tools to overcome this huge analytical task. Since the analytical laboratory was founded in 1975, the number of determinations has increased from a few thousands per year in 1975 to 100,000 in 1979 and 300,000 last year, out of which FIA methods account for 30% while the rest almost exclusively is done by ICP. The actual FIA methods used are summarized in Table II, from which follows that colorimetry and atomic absorption (AAS) and flame emission (FES) spectrophotometry are the main instrumental techniques as their combination with FIA yields a sampling frequency between 120 to 360 measurements per hour. There are six FIA systems in routine use: four with colorimetric detection, one with AAS and one attached to FES. All FIA manifolds are home-made, while the detectors, recorders and pumps mainly are imported. In addition, there are four FIA setups devoted to research, teaching and development. The permanent staff consists of three

Table I. Materials Analysed at CENA Analytical Laboratory in 1982 *).

Sample Matrix	Constituents	Quantity per year		Sample pretreatment
		Samples	Determinations	at CENA (%)
Plant materials	N, P, K, Ca, Mg, S, Fe, Cu,	9,346	105,223	90
(leaves, roots, stems, fruits)	Mn, Zn, B, Cl, Al and Na		(40,000)	
Natural waters	NH_4^+, NO_3^-, NO_2^-, Cl^-, PO_4^{3-},	5,204	119,682	10
(river, lake, rain, reservoir)	SO_4^{2-}, Ag, Al, B, Ba, Ca, Cd,		(31,224)	
	Cr, Cu, Fe, K, Mg, Mn, Na,			
	Ni, Pb, Si and Zn (Cr^{6+})			
Soils				
Extractable	Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe, Cu,	1,681	19,217	0
	Mn, Zn, PO_4^{3-}, NH_4^+, NO_3^-, Al^{3+},		(12,000)	
	Cl^-			
Total	Al, B, Ba, Ca, Co, Cr, Cu,	625	12,500	100
	Fe, K, Mg, Mn, Na, Ni, P,		(1,250)	
	Pb, Sr, Ti, V, Zn and Zr			

Table I (continued)

Sample Matrix	Constituents	Quantity per year		Sample pretreatment
		Samples	Determinations	%
Sediments (lake, river)	Al, Ba, Cd, Co, Cr, Cu, Fe, Ca, Mg, *K*, Mn, P, Pb, Ni, and Zn	440	6,600 (440)	100
Industrial Efluents (from sugar, alcohol and paper industries)	N, P, *K*, *Ca*, Mg, *S*, Fe, Cu, Mn, Zn, B, Al and *Na*	1,921	24,973 (7,000)	20
Ethanol (automobile fuel)	Na, K, Ca, Mg, Fe, Cu, Mn, Zn, Cr and Cl^-	523	5,230 (1,523)	0
Alloys	Co, Cr, Mo, Ni, Sn, Zn, Mn, Cd, Nb, Pb, Ti, V, Cu, Si and Fe	267	4,005	100

*)
Italics signify constituents always analyzed by FIA (6)
Advocate denote constituents often analyzed by FIA (6)
Numbers in brackets represent routine FIA-determinations

Table II. FIA-methods mainly used at CENA analytical Laboratory.

Constituent	Detector	Method(s)-Reagent	Number of Measurements/h
Al	Col.	Eriochrome cyanine R	120
B	Col.	Azomethine-H	60
Ca	AAS	-	120-360
Cl	Col.	Mercury thiocyanate/Fe(III)	120-240
Cr	Col.	1,5-diphenylcarbazide	120
F	Col.	Eriochrome cyanine-Zr compl.	100
Fe	Col.	o-Phenanthroline	150-180
K	FES/AAS	-	180-360
Mg	AAS	-	120-360
Mn	Col.	Formaldoxime	150
Mo	Col.	Thiocyanate/solv. extr.	40
Na	FES/AAS	-	180-360
NH_3	Col.	Nesslers reag.//indophenol blue	120-150
NO_3^-	Col./Pot.	Reduc.to NO_2//NO_3-electrode	120-150
NO_2^-	Col.	Sulfanilic acid/1-Naphthylamine	120-150
Total N	Col.	Indophenol blue	120
PO_4^{3-}	Col.	Molybdenum blue	40-150
SO_4^{2-}	Turb.	Barium chloride	120

Col.: Colorimetry; FES: Flame Emission and AAS: Atomic Absorption Spectrophotometry; Pot.: Potentiometry; Turb.: Turbidemitry.

academics and four technicians to which additional help of another three academics, four technicians and about fifteen students is temporarily attached. The majority of sample pretreatment is done outside the analytical laboratory (Table I), by the requesting counterparts, who, however, receive instructions from the analytical staff. Thus, each received sample is registered, analyzed in duplicate and the readout, in the form of a recording (Fig. 2), evaluated by comparing individual peak heights with calibration runs bracketing the sample series which typically comprize 60 measurements. The evaluation is done manually by measuring peak heights, and with the aid of a pocket calculator the results are computed and then registered into preprinted forms. All recorder charts are stored for documentation and for future reference. It can be estimated roughly that each determination requires three measurements (duplicate + standard - cfr. Fig. 2) and therefore 100,000 FIA determinations require 300,000 measurements on the six sets which have an average readout frequency of 150 s/hour. Thus the net operational time is 335 h/year, or about 1.5 hours per day per FIA instrument. To this has to be added the start up and close down time, and of course time required for all calculations, sample pretreatment, solution preparation, and maintenance.

It is obvious that it is the high frequency of measurements and efficiency of FIA, which makes this task possible. Also, the instant availability of the

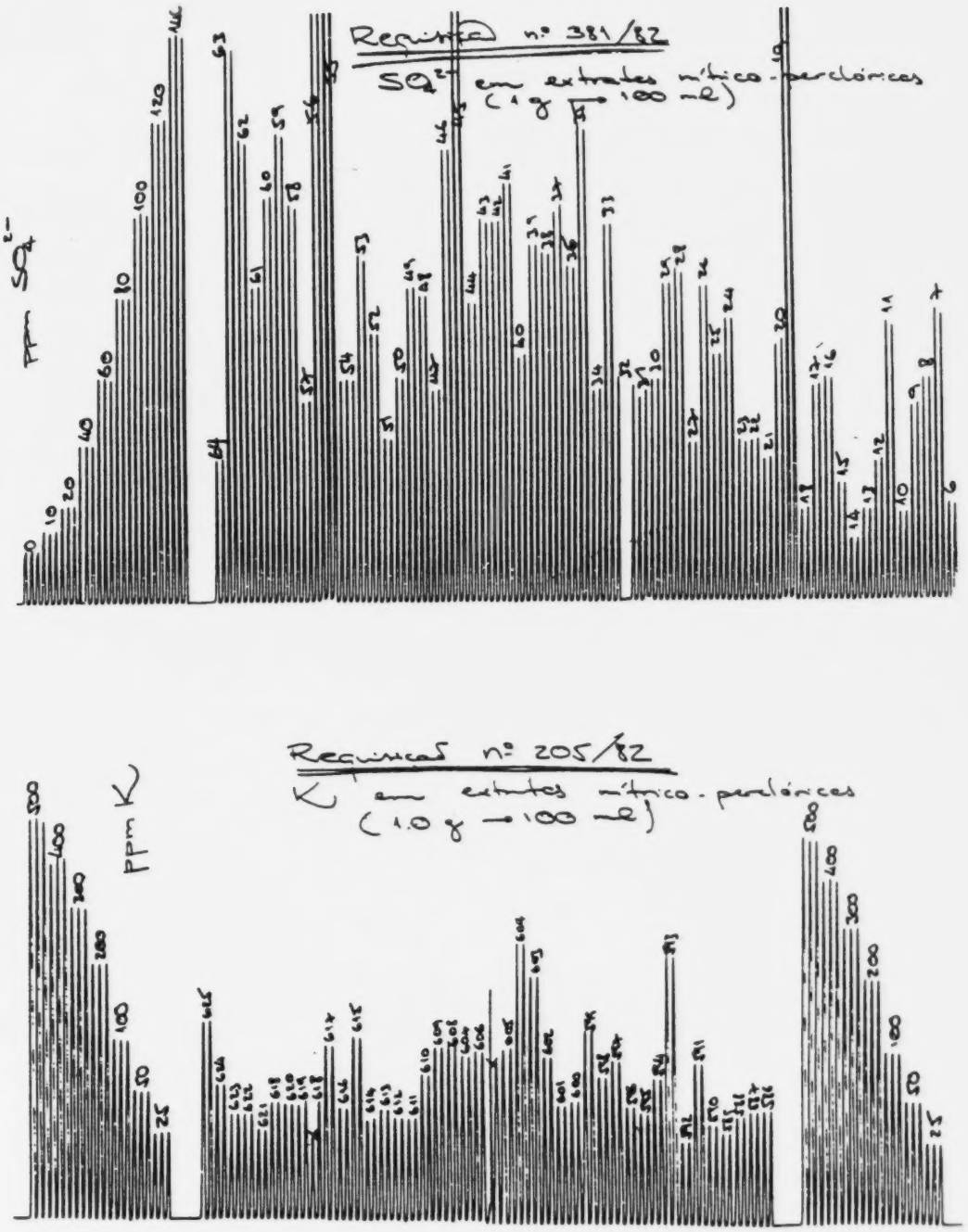

Fig. 2. Recordings for FIA routine assays of (top) sulfate by colorimetry and (bottom) potassium as determined by atomic absorption spectrophotometry.

FIA readout is invaluable as it allows the operator to react immediately and to work out proper adjustment, should the sample fall "out of range" or if any instrument malfunction occurs. This saves time and money, as no automated sample changers are needed. Besides, seen with Brazilian eyes, it is much better to invest money in people than in purchase of additional equipment., And to the visitor, the sight of an operator is infinitely more agreeable than that of a sample changer.

Indeed, there are many who come to CENA to learn the potential of FIA. They are partly students and partly those who in the past used the services of the analytical laboratory and consequently decided to acquire their own FIA expertize. Thus, presently five Brazilian institutes, of which the University of Campinas is the best known, have acquired their own FIA capability. Furthermore, at the CENA analytical laboratory five M.Sc. and three Ph.D. have been obtained on research projects aimed at flow injection method. When asked, what the single most important feature of FIA is, the head of the laboratory, dr. F.J. Krug says: "FIA is the most versatile analytical tool we know of".

There are four reasons why the analytical laboratory at CENA has turned out to be so successful: (a) There is a legitimate need for its services; (b) There is a team of experienced, highly qualified scientists who not merely supervise the routine operations, but actively improve them and develop new ones; (c) The Brazilian

researchers have shown an open-minded approach to receive a new idea, such as FIA, without any prejudice as to how continuous flow analysis should be performed, thus turning FIA into a powerful practical tool; and (d) The institute and the project has received systematic support from International organisations, a support which has been wisely managed by the Brazilian counterparts.

While the need was discussed in the introduction, it is important to realize that it is the balanced combination of research, routine tasks and academic environment, the interplay of which has proven to be ideal ground for testing and development of a new method such as FIA, i.e., the analytical laboratory at CENA has not merely served as a service organ for the requesters, but it has forced the staff actively to use their imagination and innovation to develop methods and procedures to suit the needs of the diversity of samples supplied. On the other hand the service role and work load has not allowed them to stray too far into academic types of problem solving. The result has been a stringent choice of advanced, simple and effective approaches from which many can benefit - not only in the developing countries. Some of the work of the CENA analytical laboratory has been published in international journals and its value has been widely recognized (1-7).

As in any developing country - which Brazil was in 1975 when the analytical laboratory was founded - there is lack of expertise and lack of resources. It is

besides the scope of this report to make a detailed account of how CENA was started and which support it has obtained from various sources, yet the main contributor was the United Nations Development Programme channelled through the International Atomic Energy Agency (IAEA) in Vienna. The analytical facility was partially supported by the Danish International Development Agency (DANIDA) which funded the training of several members of the CENA-staff at the Technical University of Denmark, and contributed by material and expert assistance. Following the initial stage during which most assays were done by FIA combined with colorimetry and AAS, the laboratory obtained full support also from the Brazilian authorities (CNPq, FINEP and CNEN) which in 1979 authorized the purchase of the very expensive ICP system. Now that the potential and the achievement of the laboratory has been fully recognized in Brazil it is about time that the analytical community in the socalled developed countries realize that they now can learn something in Piracicaba!

Acknowledgement. We thank professors Admar Cervellini, Henrique Bergamin F° and Eneas Salati for their support and cooperation and the United Nations Development Programme (IAEA-WHO) and the Danish International Development Agency for financial support.

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ESTABLISHMENT OF A CENTRE FOR ANALYTICAL RESEARCH AND DEVELOPMENT IN SRI LANKA

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In 1975, the Department of Chemistry in the University of Ceylon, Colombo commenced a postgraduate teaching program in Analytical Chemistry. In 1978, Professor Ramakrishna came to the Trace Analysis Research Centre (TARC), Dalhousie University on a study visit sponsored by Canada's International Development Research Centre. From this visit arose an application to the Canadian International Development Agency, from TARC, for the establishment of a Centre for research and training in analytical chemistry at the University of Colombo.

At that time the government of Sri Lanka was beginning major development programs in an effort to create one million new jobs; the literacy rate of 86 percent is among the best in Asia but 1/5 of the work force lacked jobs. The biggest project is the Mahaweli River Scheme which will open large areas to farming and will triple the island's power capacity. Sri Lanka is largely an agricultural country but a number of industries (cement, fertilizer, steel, mineral sands, paper, ceramics etc.) to help in development projects have been established. Utilization of local raw materials and exploitation of mineral resources are being emphasized.

It was recognized by individuals at the Universities of Colombo and Dalhousie that a strong analytical base was essential both for monitoring and development purposes. The application to CIDA stressed the need for training of professional analytical chemists and for a Centre oriented to projects of relevance to the development efforts of Sri Lanka. Approval was given to a five-year interuniversity program "to establish a Centre for Analytical Research and Development at the University of Colombo" in 1980; the Centre was inaugurated on January 26, 1981.

There are presently twenty people (including 8 graduate students) in the Centre. TARC's role has been to provide for training of personnel, to advise on equipment purchase and set-up of the centre and to become involved in collaborative projects. Staff from TARC have visited Colombo for various periods and personnel have come from Colombo to Dalhousie for training or co-operative research.

Space for the centre has been made available in the newly constructed Chemistry Building; funds for specialized fittings and instrumentation are being provided by CIDA. Instrument purchases have included chromatographs, spectrometers, analyzers, flow

injection systems in addition to basic supplies and equipment, air conditioners, voltage stabilizers etc. There have been delays in delivery, breakdowns and poor service from instrument suppliers but the Centre is now well established and is beginning to make contributions to welfare and development efforts in Sri Lanka. Some examples are given below.

Urban water pollution

Rivers and canals are being extensively used for disposal and dilution of city sewage; industrial effluents are also contributory factors to pollution. Changes in the levels of pollution in the urban canal system in Colombo are being monitored for correlation with population growth and industrial expansion.

Irrigation waters

An extensive area of dry zone in Sri Lanka is being irrigated through the Mahaweli project. The irrigation water flows through a system of tunnels, canals, resevoirs etc. before it reaches the fields where crops are grown. During this flow soluble salts are dissolved and the water becomes 'saline'; salts accumulate in the fields as a result of evapotranspiration affecting soil properties and crop growth. Studies of seasonal variations in total salt concentrations, sodium absorption ratios and residual sodium carbonate of irrigation water samples are in progress; such studies are essential to predict deterioration of irrigation waters so that appropriate remedial measures can be implemented.

Industrial minerals

Fifty % of the country's lime requirement is obtained from coral. The unique and valuable coral reef system is threatened with extinction as needs for lime in agriculture and the building industry increase. Large deposits of dolomitic limestone exist in Sri Lanka but attempts to use this as a limestone substitute for masonry (by calcination and slaking) were unsuccessful because of development of fractures or cracks on drying. Analytical studies identified several contributory factors and conditions for the direct application of dolomite for finishing coats have been determined. The process has been recommended to the Industrial Development Board of Natural Resources Energy and Science Authority of Sri Lanka.

Sri Lanka exports about 30,000 tons of ilmenite sands (∿ 50% $FeTiO_3$) for about $15 per ton. Rutile (>96% TiO_2) sells for fifty times as much. Studies have shown that hydroxamic acids (R-C-N-R) made from local oils (coconut oil, castor oil, sesame
O HO

oil etc.) can be used for selective extraction of titanium from ilmenite with subsequent recovery of nearly pure TiO_2 by simple pH adjustment.

Health

One of the cottage industries in Sri Lanka is the recovery of precious metals using a molten lead procedure. A comparison of blood lead levels in Sri Lankan families engaged in this practice, with controls, showed an occupational health hazard. The series of case investigations was conducted under difficult conditions because of the clandestine nature of the industry. The findings are of significance in third world countries where cottage industries abound.

Contributions have also been made to mineral prospecting (through analysis of stream sediments, biogeochemistry and remote sensing) and agriculture (projects involving coconut, rubber and tea plantations). Interlaboratory studies to provide for standardization of techniques and updating of skills of analysts in local institutions through training programs have been initiated.

As the centre has become more and more involved in local problems, it has become obvious that a services laboratory is a necessity. Many more and varied samples should be analyzed and this will only be possible if support funds for staff and equipment dedicated to this purpose can be found. The island of Sri Lanka is small (25000 sq miles) so that there is a close knit scientific community; the opportunity for co-operation and significant progress is high.

In August 21-24, 1984 there will be an international conference on "Analytical Chemistry in Development" in Colombo. This will be, in a way, the culmination of the project. The scope of the conference will be broad (e.g. Analysis of development needs and possibilities: a mutual trust process; International co-operation: problems and approaches; Analytical chemistry: the key to healthy bodies and environments; Instrumentation: problems and solutions).

SIMULATOR FOR STUDYING THERMODYNAMIC AND REACTION KINETIC PHENOMENA: A POWERFUL TEACHING AID.

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In the teaching situation a model experiment often contributes to strengthen understanding and learning of theory. To illustrate one of the most fundamental concepts in chemistry, the principle of chemical equilibrium, several mechanical devices have been designed over the years. Recently a useful machine of this kind was described (J. Chem. Ed. Sept 1978, p. 578). By mechanical analogy it demonstrates the dynamic and statistic character as well as the kinetic nature of chemical equilibria.

A similar but more versatile apparatus consisting of an extended number of reaction chambers has been designed by the author. The model system consists of plastic beads which are thrown against the walls of the Plexiglas chambers when hit by the paddles of a rotating wheel located at the bottom of each chamber. The vertical profile of two neighbouring chambers, furnished with an opening in between, provides an analogy to the energy profile of a chemical reaction of the type $A \rightleftarrows A^* \rightleftarrows B$.

The increased number of chambers of the present device makes it possible to simulate more complex kinetics than before: for instance, the study of consecutive and parallel first order reactions. In addition new applications, such as the simulation of Brownian motion, have been developed and the use of the device has even been extended to comprise a quantitative treatment of the time and temperature dependence of simulated chemical reactions.

Introduction

The present simulator, shown in Fig. 1a, is based on the same principle as that of Hauptman and Menger (J.Chem.Ed. 1978 p 578). The design differs from theirs in two respects: a) the machine consists of four Plexiglas chambers instead of two, three of which are of equal size b) the rotating wheel and the bottom part of the chambers are adjustable in height permitting one to vary the reference energy level of the system at will. Fig. 1b gives a top view of the model showing the arrangement of the chambers.

For the operation of the apparatus, a single motor drives all paddle wheels, one at the bottom of each chamber, all with the same speed. The speed setting is reproducible and continuously variable. Each speed of the rotating wheel corresponds to a thermodynamic temperature of the system. Beads at rest at the bottom of a chamber represent the internal energy U_o of the system. The temperature is then zero Kelvin and all the energy stored as potential energy of the chemical bonds, the zero point vibration energy and possible intermolecular interactions.

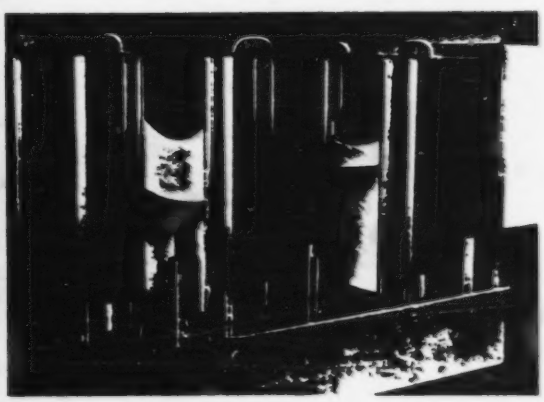

Fig. 1a

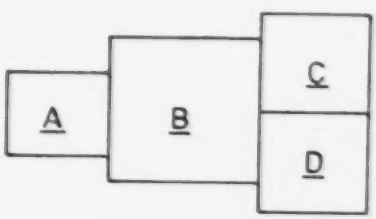

Fig. 1b
Arrangement of the chambers

Let us place a number of beads in an arbitrary chamber, *A*, and start the motor. Then kinetic energy will be supplied to the beads and throw them up and against the walls of the chamber. The distribution of kinetic energy, as visualized by the height the beads reach in the chamber, nicely simulates the Maxwell-Boltzmann statistics. The characteristic change in distribution with temperature is easily recognized following a change in speed of the paddle wheel.

Now, suppose we provide an energy barrier between two neighbouring chambers. If the temperature is high enough beads can pass the "energy barrier" to the product chamber *B* and as the temperature is uniform in the whole system there is a possibility for the beads to move freely back and forth between the chambers, and an equilibrium is established after some time. The vertical profile of the two chambers is a mechanical analogy to the energy profile diagram shown in Fig. 2.

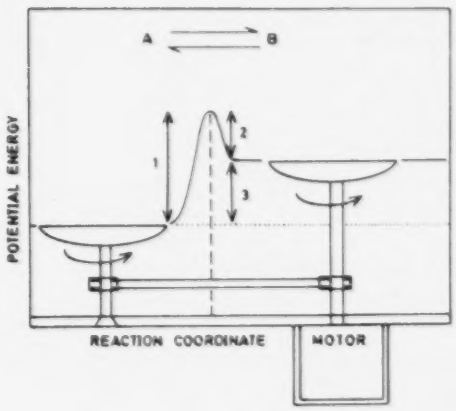

Fig. 2. Analogy between simulator model and energy diagram.
1. Activation energy for the reaction A → B.
2. Activation energy for the reaction B → A.
3. $\Delta H^{\ominus}$ for the reversible reaction.

A constant rotational speed of the paddle wheel represents a well defined thermodynamic temperature of the system. The majority of beads collide with the paddles at the pheriphery of the rotating wheel. The peripherial speed can then be expressed as

(1) $$v_p = \nu_{rot} \cdot l$$

where l is the circumference of the wheel and ν_{rot} is the angular velocity of the paddle wheel, expressed in radians/sec. The beads are supplied kinetic energy

(2) $$\varepsilon_k = \tfrac{1}{2} m v_p^2 = \tfrac{1}{2} m \, \nu_{rot}^2 \cdot l^2$$

which also constitutes translational energy and then as such can be written

(3) $$\varepsilon_t \propto k_B \cdot T$$

where k_B is the Boltzmann constant and T the absolute temperature. Thus combining (2) and (3) we have

(4) $$T \propto \nu_{rot}^2$$

which allows quantitative of measurement of various parameters as a function of temperature.

A collection of quantitative experiments and new demonstrations within the fields of themodynamics and kinetics using the simulator is reported in the following sections.

Energy levels and the Boltzmann distribution

In order to study the bead-energy distribution quantitatively, one of the walls of a chamber was replaced by a special device in the form of a box containing a number of plates, simulating energy levels, which can be seen in Fig. 1. By pushing all the plates at the same time rapidly into the chamber, the beads in motion are collected on the plates and the distribution can be established. Using the Boltzmann equation for the distribution of particles between two energy levels

$$(5) \qquad \ln \frac{N_j}{N_i} = - \frac{\Delta\varepsilon}{kT}$$

a plot of the left hand side of the expression versus 1/T will be linear, giving the energy separation $\Delta\varepsilon$.

Experimentally we have used 200 beads, measured the distribution at different temperatures, and plotted $\ln \bar{N}_j/\bar{N}_i$ versus $1/\nu^2_{rot}$. The quantity $\bar{N}_j$ is the average number of beads in energy level j obtained from ten experiments at the same temperature. The result from three different ratios for increasing energy separation is depicted in Fig. 3. A linear relationship is obtained and from the slopes the separation of the energy levels are calculated and found to be directly proportional to the measured distances between the plates in the box.

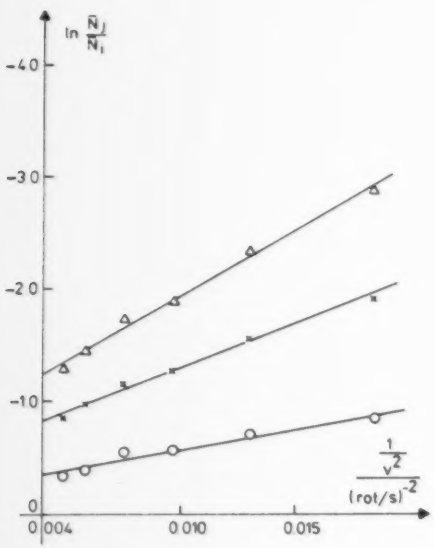

Fig. 3
A Boltzmann representation of the distribution of beads between two energy levels at different rotational speeds.

⊙: j = i + 1
x: j = i + 2
Δ: j = i + 3

The simulator as a model for the entropy concept

The beads in motion give a macroscopic mechanistic picture of certain aspects of the concept of entropy by visualizing

the random arrangement of the particles of the system. It is observed how the freely movable particles spontaneously and randomly assume the most probable configuration. The entropy of the system is an extensive property, composed of the sum of the different parts of the system. It can be changed in two ways, either by interaction with the environment or by internal processes within the system.

In connection with the introduction of the concept of entropy demonstrations of the following types can be used as a basis for a discussion of the fundamental factors that influence the entropy of a system: a) The same number of beads in two separate chambers of the same size (*C* and *D*), maintained at the same temperature. b) Different number of beads in *C* and *D* at constant temperature. c) The same number of beads in separate chambers of different size (*A* and *B*) at the same temperature. d) One chamber is loaded with "molecules" (prepared by two beads joined by a spring). At elevated temperature dissociation occurs. e) Beads at rest in a chamber simulated the crystalline state at temperature T = O. As the temperature is increased, the melting and vaporization processes are simulated. f) Chambers *C* and *D*, being on the same height, are loaded with beads of different colours. The wall between them is removed and the mixing process studied.

Equilibrium constant and temperature

The influence of temperature on the position of equilibrium and the role played by $\Delta\bar{H}^{\ominus}$ and $\Delta\bar{S}^{\ominus}$ in the relation $\Delta\bar{G}^{\ominus} = \Delta\bar{H}^{\ominus} - T\Delta\bar{S}^{\ominus} = -RT\ln K$ has been nicely demonstrated and discussed by Hauptman and Menger in their article.

The equilibrium constant for the reaction $A \rightleftarrows B$ is determined by the expression

$$K = \frac{[B]}{[A]} = k \cdot \frac{\bar{m}_B}{\bar{m}_A}$$

where $\bar{m}_A$ and $\bar{m}_B$ are the mean values of the mass of beads in the reactant and product chambers for ten repeated experiments. The constant k is the volume ratio between the chambers.

Quantitative measurements have now been performed to obtain the equilibrium constant as a function of rotational speed for a simulated reaction taking place between chambers *A* and *B*, being of different size. A plot of ln K versus $1/\nu_{rot}^2$ is shown in Fig. 4 and confirms the linear relationship between lnK and 1/T predicted by the expression

$$\ln K = -\frac{\Delta\bar{H}^{\ominus}}{R} \cdot \frac{1}{T} + \frac{\Delta\bar{S}^{\ominus}}{R}$$

From the slope and intercept $\Delta\bar{H}^{\ominus}$ and $\Delta\bar{S}^{\ominus}$ can be evaluated. Furthermore, in a similar experiment, now using chambers *C* and *D* being of the same size, we can convincingly show that the intercept in this case is zero, implying that $\Delta\bar{S}^{\ominus} = 0$ and thus the equilibrium constant is only determined by $\Delta\bar{H}^{\ominus}$ under those conditions.

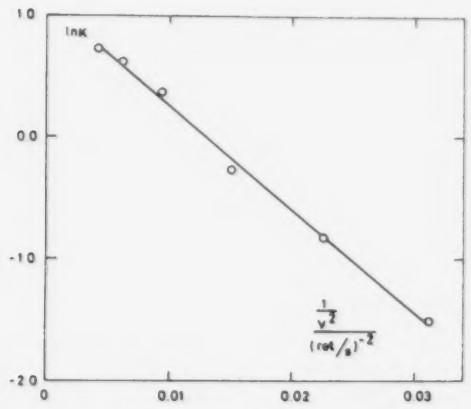

Fig. 4. The temperature dependence of the equilibrium constant from measurements of the equilibrium constant at different rotational speeds.

First-order reaction

If we replace one of the rotating wheels in chamber *B* by a bowl that can catch the beads coming from chamber *A*, we can study a simulated first-order reaction of the type $A \overset{k_1}{\rightarrow} B$ with the rate constant k_1. We place a suitable number

of beads in *A*, supply enough energy to make it possible for the beads to pass the energy barrier between the chambers and catch them in *B*. The experiment is repeated at the same temperature, interrupted at different points of time and the concentration of beads remaining in *A* is determined. By means of the expression $\ln[A] = f(t)$ the rate constant k_1 is evaluated. In a similar manner the reversible reaction $B \overset{k_1'}{\underset{k_1}{\rightleftharpoons}} A$ can be studied under the same conditions and k_1' determined. Results from experiments of this type using 200 beads is illustrated in Fig. 5. Rate constants $k_1 = 0.032 s^{-1}$ and $k_1' = 0.11\ s^{-1}$ are obtained. Thus a value of the equilibrium constant defined as $K = k_1/k_1' = [B]/[A] = 0.29$ is found. This is in good agreement with the directly measured equilibrium constant, using both rotating wheels, which is found to be $K_m = 0.28$. The experiment convincingly shows that the equilibrium constant is linked to the rate constants of the forward and reverse steps in a reversible reaction.

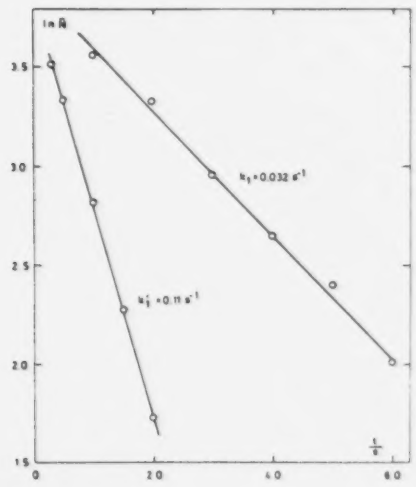

Fig. 5. First-order reactions A→B and B→A with rate constants k_1 and k_1', respectively.

Reversible first-order reaction

The rate expression for a reversible first-order reaction $A \rightleftharpoons B$ with rate constants k_1 and k_1', respectively can also be

tested directly by a properly designed experiment with the simulator. The following rate expression holds

$$(8) \qquad \frac{d[A]}{dt} = - k_1[A] + k_1'[B]$$

If only A is present from the beginning we obtain the solution

$$(9) \qquad \ln \frac{[A]_o - [A]_{eq}}{[A] - [A]_{eq}} = (k_1 + k_1') \cdot t$$

A plot of the left hand side of eqn. 9 as a function of time predicts a straight line with slope $(k_1 + k_1')$ which combined with known equilibrium constant $K = k_1/k_1'$ will give the rate constants.

The experimental arrangement is identical to the one described in the previous section except that both chambers are equipped with the rotating wheels. Chamber *A* is loaded with beads and the simulated reaction is interrupted at different points of time before equilibrium is established and [A] is determined. Also the equilibrium concentration, $[A]_{eq}$, is measured after a sufficiently long period of time. Using these parameters and the known initial concentration $[A]_o$ eqn. 9 can be applied. Data from a typical experiment are represented in Fig. 6 and found to be linear. If we combine the slope with the directly measured value of the equilibrium constant, K_m, obtained after a sufficiently long time, the rate constants $k_1 = 0.037\ s^{-1}$ and $k_1' = 0.085\ s^{-1}$ were calculated. These values compare well with the corresponding ones determined for the forward and reverse reactions reported in the previous section.

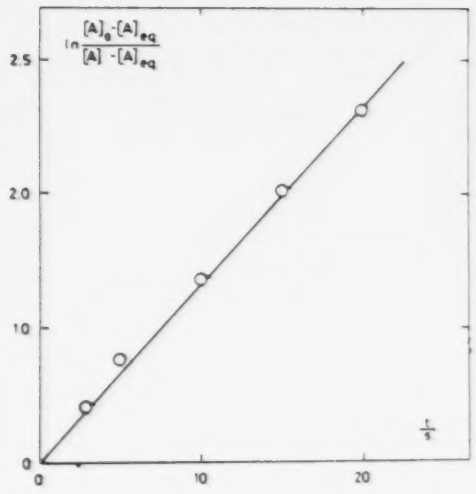

Fig. 6 Reversible first-order reactions $A \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} B$

Second-order reaction

In this experiment two different kinds of beads are allowed to "react" with each other in *A*. Beads passing the energy barrier to *B* are identified as reaction products. Thus the reaction studied is of the type A + B → C + D. Suppose that the reaction is a bimolecular elementary reaction, then the rate expression is given by

$$(10) \qquad -\frac{d[A]}{dt} = k_2[A][B]$$

with the solution

$$(11) \qquad \ln \frac{[A]_o[B]}{[B]_o[A]} = ([A]_o - [B]_o)\, k_2 t$$

Experimentally the concentrations of A and B remaining in *A* are measured at different points of time. Data using eqn. 11 are reproduced in Fig. 7 for an original mixture of 170 plastic and 90 paper beads. We find a reasonably good linearity in the time domain when interaction between the different beads occurs. The experiment illustrates quite clearly the general treatment of a second-order reaction with different initial concentrations of the reactants.

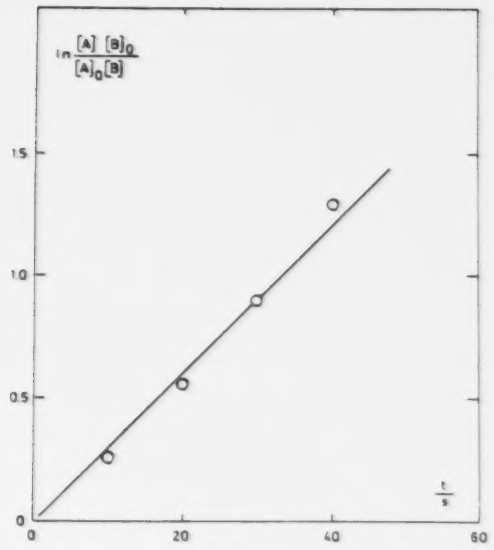

Fig. 7
Second-order reaction
$A + B \xrightarrow{k_2}$ prod.

Consecutive reactions

The simplest consecutive reaction represented by $A \xrightarrow{k_1} B \xrightarrow{k_1'} C$, consists of two irreversible first-order steps with rate constants k_1 and k_1'. Examples of reactions that follow this pattern are: radioactive disintegration of some elements and the pyrolysis of acetone.

For this demonstration three of the chambers are utilized. By adjusting the energy barriers, the level of the bottom part of each chamber and the speed of the rotating wheels, we can ensure irreversibility of the reaction and decide the magnitude of the rate constants k_1 and k_1'.

Experimentally, beads are originally placed in, say, *A* and as the motor is switched on they pass over to *B* and then further on, to be finally trapped in *C*. The concentrations of A, B and C are measured after "freezing" the reaction at different points of time after the start. The measured concentration dependence on time for the three components is given by the points in Fig. 8 which represents a typical experiment of this kind with $k_1 > k_1'$.

The set of differential equations describing the change in concentration with time for the reaction A→B→C is

$$d[A]/dt = - k_1[A] \quad (12)$$

$$d[B]/dt = k_1[A] - k_1'[B] \quad (13)$$

$$d[C]/dt = k_1'[B] \quad (14)$$

The mathematical treatment, with all the beads initially in *A*, leads to the following expressions for the concentrations:

$$[A] = [A]_o \exp(-k_1 t) \quad (15)$$

$$[B] = \frac{k_1 [A]_o}{k_1 - k_1'} [\exp(-k_1 t) - \exp(-k_1' t)] \quad (16)$$

$$[C] = [A]_o \left[1 + \frac{1}{k_1 - k_1'} (k_1' \exp(-k_1 t) - k_1 \exp(-k_1' t))\right] \quad (17)$$

The rate constants k_1 and k_1' were evaluated from experimental data at the point in time when $d[B]/dt = 0$ and found to be $0.036\ s^{-1}$ and $0.060\ s^{-1}$, respectively. These values were used to calculate theoretically the concentration of the three components as a function of time. The result is represented by the curves depicted in Fig. 8 and the method gives a reasonably good consistancy between theory and experiment.

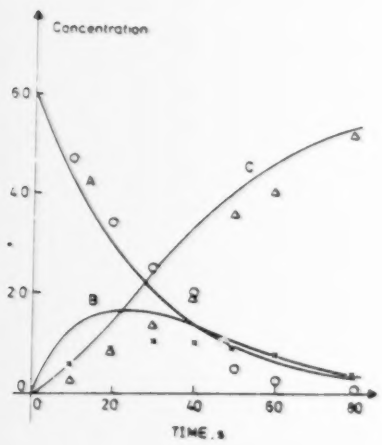

Fig. 8 Consecutive first-order reactions A → B → C

The temperature dependence of the reaction rate

The influence of temperature on the rate constant is governed by the Arrhenius equation

$$k = A \exp(-E_a/kT) \qquad (18)$$

In order to investigate this law, the rate constant is measured for the simulated reaction A→B at different rotational speeds of the paddle wheel. A plot of ln(k) versus $1/\nu^2_{rot}$ is shown in Fig. 9 and from the slope of the linear relationship found, the activation energy, E_a, may be estimated. Hauptman and Menger have thoroughly treated how the shape of the barrier profile can be associated with $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ in the theoretical rate equation derived by Eyring and they have furthermore discussed how different shapes of the profile affect the equilibrium constant.

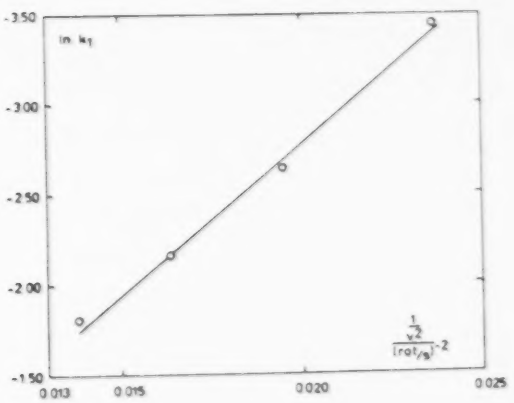

Fig. 9
Application of Arrhenius eqn. for the activation energy to the dependence of the rate constant on the temperature for a simulated reaction of the type A→B.

The steady state principle

The mathematical treatment of rate equations from chemical reactions involving shortlived intermediates is considerably simplified using the steady state assumption. If a reactive intermediate, A^*, is assumed to rapidly attain a low and constant concentration, then the steady state approximation $d[A^*]/dt = 0$ may be utilized.

For this demonstration a reaction of the type $A \rightleftarrows A^* \rightarrow B$ is considered. The apparatus is furnished with a rectangular platform which is placed in the opening between two of the chambers. The platform is covered with cloth to increase friction, thus prolonging the stay of beads A^* arriving thereon. Another frame also covered with cloth, is inserted in the opening between the chambers, leaving only a small distance free to the platform. Beads on their way to pass from *A* to *B* collide with the vertical frame, drop down onto the platform and rest there for a short period of time. After colliding with other arriving beads, they fall back either to the product chamber *B* or to the reaction chamber *A*, in the latter case with the possibility to be activated again. The steady state principle is nicely demonstrated by the constant small number of beads A^* resident on the platform during the experiment.

Unimolecular gas-phase reactions

The kinetics of thermal decomposition or isomerization of gas-phase reactions was originally elucidated by Lindemann in 1922, who suggested the following mechanism for a reaction leading to decomposition:

(19) $A + A \rightleftarrows A^* + A$

(20) $A^* \rightarrow B + C$

In order to explain the observed first-order kinetics for reactions of this kind, the unimolecular decomposition of the activated molecule A^*, formed by collision, is assumed to happen after a delayed period of time. During this time redistribution of the energy supplied by the collision process takes place within the molecule. The energy is transferred into particular chemical bonds, causing high amplitude vibrations and eventually leading to rupture and decomposition of the molecule. However, some of the activated molecules A^* can undergo another collision with an energy-poor molecule during the time or rearrangement and thus become deactivated before being able to decompose. This is illustrated by the reverse reaction 19. The general theory for unimolecular reactions was later developed further by Kassel, who introduced refinements based on quantum theory.

For the present demonstration Fig. 10 depicts schematically the design and use of the special device which is attached to one of the chambers of the simulator. The upper half of one of the walls of the chamber has been replaced by a frame which is covered with cloth and positioned a small distance outside the chamber. The lower part of the frame consists of a reservoir provided with a small opening at the bottom. The paddle wheel 1 hits the beads, throwing them around randomly and a bead such as 2 denotes a normal undisturbed molecule. Those beads 3 that collide with the cloth wall are molecules activated by collision and they fall down and become temporarily trapped in the reservoir 4. Provided that a sufficient number of activated molecules are formed, the reservoir will eventually be filled up even if some beads, 5, are contineously leaving through the bottom of the supply. These beads, 6, symbolize the particular molecules that are chemically transformed to reaction products. When the reservoir is full, an overflow is observed and beads, 7, fall back into the original chamber. They represent

molecules which are deactivated before becoming products due to a collision with another energy deficient molecule, thus becoming a new potential reactant.

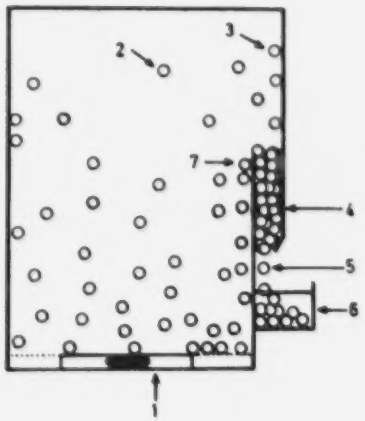

Fig. 10. The principle for the simulator used as an analogy to illustrate the application of the collision theory to unimolecular reactions. 1. Paddle wheel at the bottom of one chamber. 2. Normal molecule. 3. Molecule activated by collision. 4. Reservoir containing activated molecules. 5. Molecules which undergo chemical reaction. 6. Reaction products. 7. Activated molecules being deactivated by collision with energy deficient molecule.

The simulation emphasizes several important features of the theory for unimolecular gas phase kinetics. It clearly demonstrates the time lag existing between the activation process and the formation of the reaction products. It also shows that the number of molecules in the activated state at any time does not depend upon the rate of activation. Thus a statistical equilibrium of activated molecules is attained and maintained by the activating and deactivating processes. Consequently, the reaction rate is not dependent on the collision frequency under these conditions. On the other hand the reaction rate is dependent upon the actual number of activated molecules in the steady state (reservoir).

If the rate of activation is lowered, by reducing the number of beads (lowering the pressure), then equilibrium is no longer maintained and the reaction rate is found to decrease, now being dependent on the frequency of collision.

Brownian motion

In this experiment one of the chambers is loaded with a large number of beads representing solvent molecules. A bigger bead, symbolizing a colloidal particle, is hung from a string in the middle of a chamber. The motor is switched on and the rotational speed of the paddle wheel is increased until the small beads are bombarding the big one which then excecutes an irregular motion pattern and give a three dimentional macroscopic qualitative picture of the phenomenon. The demonstration clearly shows that the summated impacts of solvent molecules on the sides of the colloide particle do not at every instant cancel exactly and constitutes a visual confirmation of the random kinetic motion assumed for a molecular assembly at any temperature above absolute zero. The simulation has been used as a valuable complement to the direct observation of the phenomenon in the ultramicroscope using, for instance, a silver colloid suspension.

Summary

The present article has the purpose to present the extended use and emphasize the potential power of the bead simulator. It has been utilized by the author in different teaching situations such as lecture demonstrations and experimental project work for small groups of students.

Of course one must be fully aware that a simulation, no matter how well designed, can never replace nature as such and that sometimes there are even rather serious limitations.

Nevertheless, in connection with the introduction of a new concept it serves a useful, if temporary, purpose. The author has had many stimulating discussions concerning the use of the apparatus at all levels of sophistication with people of all ages, children, students and professionals and new applications are contineously being developed. A very interesting observation is that students who are usually reticent often become activated by the use of the simulator and stimulated to spontaneously discuss the strength and weakness of the particular demonstration.

Today many of the experiments described can of course be performed by computer programs, but the statistical dynamic character of the present simulations and the possibility to quantitatively treat collected data and compare with theory has been found to be appreciated by the students. In conclusion, it is evident from what has been said that the device is useful in many different contexts during the introductory general and physical chemistry courses.

LOW-COST EQUIPMENT FOR CHEMICAL EDUCATION

- A Review of an IUPAC/UNESCO project at the University of Delhi

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Introduction

The Committee on Teaching of Chemistry (CTC) of IUPAC in collaboration with UNESCO and the Committee on Teaching of Science (CTS) of ICSU has sponsored a project at the University of Delhi since October 1979 for development and fabrication of simple equipment using local materials and local know-how. An interdisciplinary team consisting of chemists, physicists and technicians have devised low-cost versions of several instruments, accessories and experiments suitable for use at senior school and junior university/ college level. An important feature of the work has been the involvement of a large number of students. This has been encouraged as it is felt that students can learn as well as contribute many useful ideas in constructing simple instruments. Another important feature is the exclusive use of made-in-India components. This stresses self-reliance and also adds a challenge to the designing problem, since what is available locally is certainly much more restricted than what is available internationally. It should be mentioned that the core team and the students have been working in their spare time and that none of them have been trained in either instrumentation or electronics. This has helped to create an informal, non-professional atmosphere where the accent is on simplicity of approach.

Review of the Development Work

It was decided to begin with the design and the fabrication of a pH meter and a conductometer because they can be used in many ways at the senior school and junior college level. Two integrated, low-cost packages have been developed around these instruments. Each package consists of the equipment (several models), accessories (electrodes, cells etc.) and about 25 tested experiments from different areas of chemistry. Other types of equipment where the work is either complete

or likely to be so very soon include (a) a polarimeter (b) a colorimeter and (c) a timer. A brief description will now be given of the different pieces of equipment developed in the project.

pH meter: As many as seven versions have been made to suit different requirements. The cost price of these models range from US $12 to $50. Their common features are:

(i) All the models employ a single operational amplifier (opamp). This feature has been dictated by cost considerations as well as by the challenge that a circuit poses when required to be designed using a minimum number of components.

(ii) With one exception, the models employ the general purpose 741 opamp which was the only opamp made in India when the project started. The sole exception employs an imported 3140 type which is a high impedance opamp thereby permitting the use of a glass electrode. This model has been built to show to the local teachers that when specialised opamps start becoming available in India, the instruments will become cheaper, simpler and more versatile.

(iii) All the models require that the pH value is calculated from the measured EMF via the Nernst Equation. This is considered good pedagogy as a student user realises that a pH meter is only a millivoltmeter with the Nernst Equation underlying the conversion. It also provides the user with temperature dependent corrections.

To enumerate the differences between the models, it is useful to consider the three principal parts [i.e. (a) power supply, (b) constant current source and (c) main operative circuit] separately.

Power supply: Two of the models can be used with batteries, the rest operate on 220 V, 50 Hz. RC filtering has been used because the principle is easy to understand. Three stage filtering is necessary if an accuracy of ± 0.01 pH unit is desired but fewer stages are required if lesser accuracy is acceptable.

Constant current source: Reliable and accurate measurement of pH also demands that a negligible current (10^{-8}A or less) is drawn from the electrochemical cell. To achieve this a constant current source is incorporated in all the models except the one designed for the school level.

Main operative circuit: The school model uses a 'comparator' circuit but all the others are based on the 'voltage to current' converter circuit. Both these circuits are well known in the literature. However, a variant of the voltage to current converter used in our most sophisticated model (which permits the use of a glass electrode with a single 741 based circuit) does not appear to be equally well-known.

Conductometer: Two versions have been developed. The one costing US $40 is considered suitable for undergraduate level while the ultra low-cost model (US $8) is probably adequate for school level work.

The more expensive model employs a single 741 opamp in the multivibrator configuration. The principle underlying the circuit is as follows. The frequency of a multivibrator is controlled by the resistance arm (e.g. a conductance cell) if the capacitance is held fixed. The frequency is measured as a current via a frequency sensitive network. The conductance of a solution can thus be obtained by measuring the current after the instrument has been calibrated using standard resistances.

The school model employs a Wheatstone bridge circuit with phase sensitive detection via two LEDs and a transistor. Its operating principle utilizes the fact that the base and collector voltages have to be of the same sign to activate a transistor.

Polarimeter: A combination of two polaroid slides - one used as a polarizer and the other as an analyzer - is used to determine the angle of rotation of the plane of polarization by an optically active substance. Three LEDs (green, yellow and red) are used as light sources which permit one to observe the dependence of specific rotation on frequency of light.

This model is based on an idea borrowed from a polarimeter built at the Royal Danish School of Educational Studies,

Copenhagen. Its cost price is estimated to be about US $7.

Colorimeter: The highlights of this instrument - which is still under development - are the use of (i) an automobile lamp as the source of white light, (ii) a pair of ordinary prisms in series for dispersion and (iii) a phototransistor as the detector. The sample tube is rigidly fixed in the path of the white light. It is alternately filled with the sample solution and the reference solution. This arrangement eliminates the need of careful optical matching of sample holders. The cost price of the model is likely to be about US $50.

Timer: This is a straightforward design in which one IC 555 is used in a timer circuit while another IC 555 is used in an oscillator circuit. The pulse from the timer is used to interrupt the oscillator signals. The timer has the following intervals (in seconds): 26, 49, 72, 100, 120 and 230. However, any other values can be chosen by altering one or more of the resistances between the power supply and the IC.

The cost price of the timer is about US $10. It has been found to be very convenient for kinetic studies in conjunction with the pH meter and the conductometer described earlier.

Accessories for pH meter and conductometer: When the equipment for measurement of pH and conductance becomes low cost, it is necessary to find cheap substitutes for platinum electrodes and platinum foil conductance cells, otherwise one will have the absurd situation of accessories costing more than the instruments!

It has been found that a carbon rod extracted from a used dry cell is a completely acceptable substitute for platinum after the electrode is cleaned with dilute chromic acid. The carbon rod can be used for pH measurements via a quinhydrone electrode and also for redox titrations. A carbon electrode can be easily electroplated with copper, zinc etc. to yield a variety of low-cost electrodes. Nearly zero-cost conductance cells of different designs made with carbon electrodes have been found to function as well as the commercial conductance cells available in India, costing about US $50 and upwards. Several ion-selective electrodes and a glass electrode made from solf-glass test tubes complete the useful range of zero-cost

accessories for use with the low-cost pH meters and conductometers.

Propagation:

The philosophy of the Delhi Project is to spread the approach rather than distribute or sell the instruments. The following Workshops have been held so far in India for training teachers and students:

Madras (July 1981); Mysore (October 1981); Delhi (November 1982); Hyderabad (November 1982); Chandigarh (January 1983) and Delhi (June 1983).

While most of these workshops have concentrated on familiaring the participants with the low-cost instruments, the Hyderabad and the Delhi Workshops also involved fabrication. In the former, twenty teachers assembled twenty pH meters and conductometers in one week and took the instruments to their institutions for student usage. The Delhi Workshop, held under the auspices of the University Grants Commission (India) in June, 1983, is noteworthy because twelve students assembled 50 instruments in three weeks while learning the theory of operation and the testing procedure. The fabricated instruments will be sent to selected institutions all over India for field-testing so that an assessment under realistic classroom conditions can be made.

Conclusion:

All the ideas in the project like using opamps for instrument design, the particular circuits for different instruments, use of carbon electrodes, the making of simple ion-selective electrodes and of soft glass test-tube glass electrodes, etc. are well known. No originality is thus claimed in any of these matters. What the project has attempted to do is; (i) to bring together chemists, physicists and technicians, (ii) to develop a low-cost package around an instrument consisting of equipment, accessories and experiments, (iii) to involve students and teachers in the development, testing and fabrication process, (iv) to combine training with production (i.e. participants come to learn in Workshops but they <u>also</u> produce finished goods) and (v) to 'sell' the do-it-yourself approach by personal involvement.

The response generated by this activity inside and outside India augurs well for its future. However, this is only the beginning and much remains to be done. Unless and until the low-cost packages reach the student laboratories and permit the young generation to cultivate innovativeness, nothing of significance has been achieved. It is hoped that generous support from the international scientific community will come to help at least a partial realisation of this objective.

EXPERIMENTAL INSTRUCTION AND TRADITIONAL BEHAVIOUR PATTERNS IN THE DEVELOPMENT PROCESS

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An increasing number of conferences, seminars and workshops are preoccupied with the problem of low-cost educational materials. This creates the impression that improvements in instruction in the natural sciences are predominantly a question of a lack of teaching aids. But the generally deplorable practice of cramming, where the teacher lectures and the students absorb information on which they can be examined without giving it any thought and which is rarely of any use, must make one think.

For example, in a number of schools one finds supplies of teaching aids which have never been unpacked or are rarely used - an indication that while there may be different incentives as political, social and cultural, to procure them, there is no motivation on the part of the teachers to use them for educational purposes. It is not always just strict examination requirements, bad pay or inadequate classrooms, or similar factors which are not directly dependent on the teacher, which prevent experimentation on a broader basis; there may also be other factors profoundly involved with the teacher's social and cultural image of himself, which hinder changes in his teaching style. In short: there is a certain demand for teaching aids but no intention to use them.

Experience of teaching work in various countries indicates that a more comprehensive, differentiated view of the problem of changes in teaching style must be taken, that this problem should not merely be seen as dependent on quantifiable shortcomings.

The discrepancy which can often be noted between the demands formulated in programmes and the persistance of traditional behaviour patterns in education leads one to wonder whether, in the field of education, there might not be other approaches to natural phenomena more closely related to the sociocultural environment than those formulated by the science. In any event, teachers experience considerable difficulties in accepting "modern" teaching methods which contradict their own social and cultural patterns.

Personal experience in various countries indicates that simple teaching aids can successfully be produced by the teachers themselves. Like other attempts at modernisation, however, this one will also remain futile, in the last analysis, unless it proves possible to develop appropriate strategies to lead the teacher to carry out experiments which have been methodically considered and in which he takes a personal interest. In this context, at present, more questions can be asked than answers provided.

PRODUCING ONE'S OWN TEACHING AIDS - A FASTER, CHEAPER ALTERNATIVE WAY TO MAKE TEACHING OF NATURAL SCIENCES BY EXPERIMENT ACCESSIBLE

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Satisfying basic needs has particular importance in the development programmes of many countries. Today, reading, writing and arithmetic are included in the list of basic needs, which is why more and more primary schools are being built and more and more teachers appointed. An increasing number of people are interested in learning more. And at the higher levels of the educational system the demand for more and better training is growing. This means that, in the establishment and development of the educational system, problems are being encountered both with regard to the actual availability of resources and their distribution between the various levels and sectors.

Training schemes in virtually all countries emphasise the particular importance of education in the natural sciences for economic and social development. Often, however, because other essentials of life are even more important, teachers cannot be provided with even the simplest teaching and learning aids to make this instruction cost effective.

For example, in many cases financial restrictions make it impossible either to import sufficient quantities of teaching aids or to start mass production of them in the country. This particularly affects experimental work in the natural sciences, where instruments and other materials are required in addition to books. In such situations alternative methods of making experimental work possible at low cost and within a very short time in spite of the pressure of an increasing number of pupils ought to be discussed. For this purpose the current experience of several countries is available.

One possible alternative, for example, is the active involvement of teachers and pupils in improving the availability of teaching

aids in their educational environments. There is nothing new about this idea, which has been widely practised against a variety of backgrounds. For instance, in the years just after the Second World War, teachers in Central Europe working in urban schools which had been severely damaged or transferred to temporary premises or in simple country schools, drew on their practical experience to construct appropriate teaching aids and develop simple but significant experiments for all aspects of the natural sciences. On other continents, teacher training institutions include for pedagogical reasons the design and production of individual teaching aids in the training programme.

We have evaluated the results of these approaches to self-made teaching aids and as a result have designed a basic kit which enables experimental work in the natural sciences to be undertaken. The items enable simple but significant experiments to be carried out at the primary and lower secondary level, particularly in chemistry and biology.

Construction of the equipment by the users is made easier by the application of the following principles:

- the individual components are so designed that they can be produced in 2 to 3 weeks, even by persons without particular manual skills using only simple tools.
- the items of the kit are based on a small number of materials, almost all of which can be obtained locally. They are deliberately drawn from the environment of teachers and pupils.
- material and production costs are so low that they do not make excessive demands on limited budgets.
- materials and tools for seminars in remote locations can be prepared and packed into two easily transportable cases.

The items which can be packed in a convenient, lockable case have a number of advantages:

- the user is familiar with individual components, and will hence have no worries about using them.
- the materials required to carry out experiments at various levels are immediately available.
- replacement and supplementary parts can be produced at principal towns and do not involve long delivery formalities.
- the low material value means that theft is not a problem.
- a large number of simple experiments can be carried out with familiar materials, so that even inexperienced teachers can noticably improve their teaching within a very short time.
- no special rooms are necessary to carry out the experiments.
- use of the kit brings greater dexterity in experimenting, so that existing imported teaching aids can be used without misgivings, more frequently and hence profitably.

Simple, standardised but by no means improvised teaching aids can be made by teachers as part of their basic or advanced training. Pilot seminars, some supported by the German Agency for Technical Cooperation (GTZ), have been held in Afghanistan, Bolivia, Nicaragua and Columbia, and teachers have successfully produced their own teaching aids and then carried out experiments with them. In the process, various ways of organizing seminars for advanced in service teacher training were tested. All these seminars consisted of two parts:

- the first part was devoted to providing technical working instructions on how simple teaching aids can be made for demonstration purposes and instructing groups of students. The participants then produce these teaching aids from local meterials.

- in the second part, the teaching aids produced were used for experiments, and discussions were held with the participants about possible applications for educational purposes. The knowledge thus obtained can be of direct benefit to teaching, as the participants take "their" teaching aids with them.

Holding these seminars requires a workshop equipped with simple tools. The ideal number of participants is 15 to 20.

Three basic types of seminar have proved practicable:

- exended seminars lasting from 2 to 3 weeks in which the participants learn how to produce and assemble a basic kit for experiments, and how to use it for teaching.

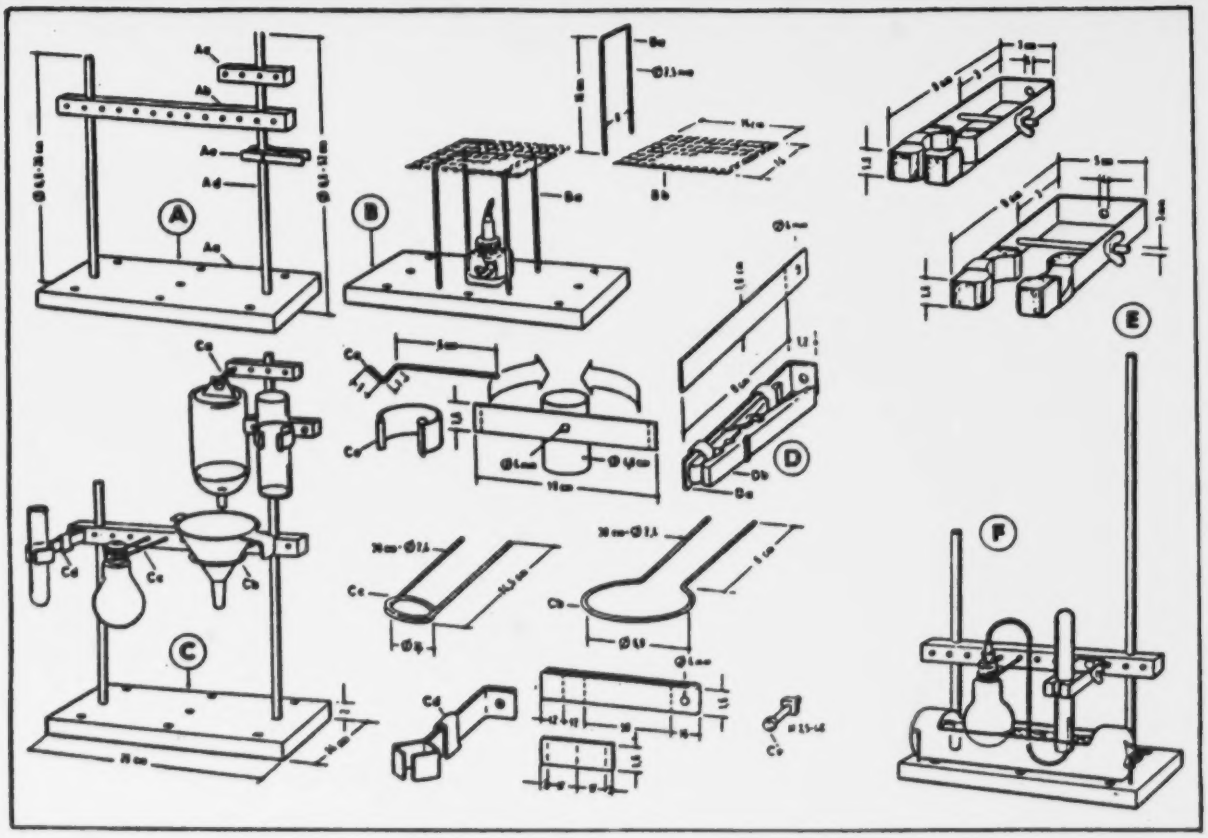
- shorter seminars lasting from 2 to 6 days which are intended to provide an introduction to the manufacture and use of teaching aids. The participants make selected design-specific and subject-related types of teaching aids and carry out experiments with them.

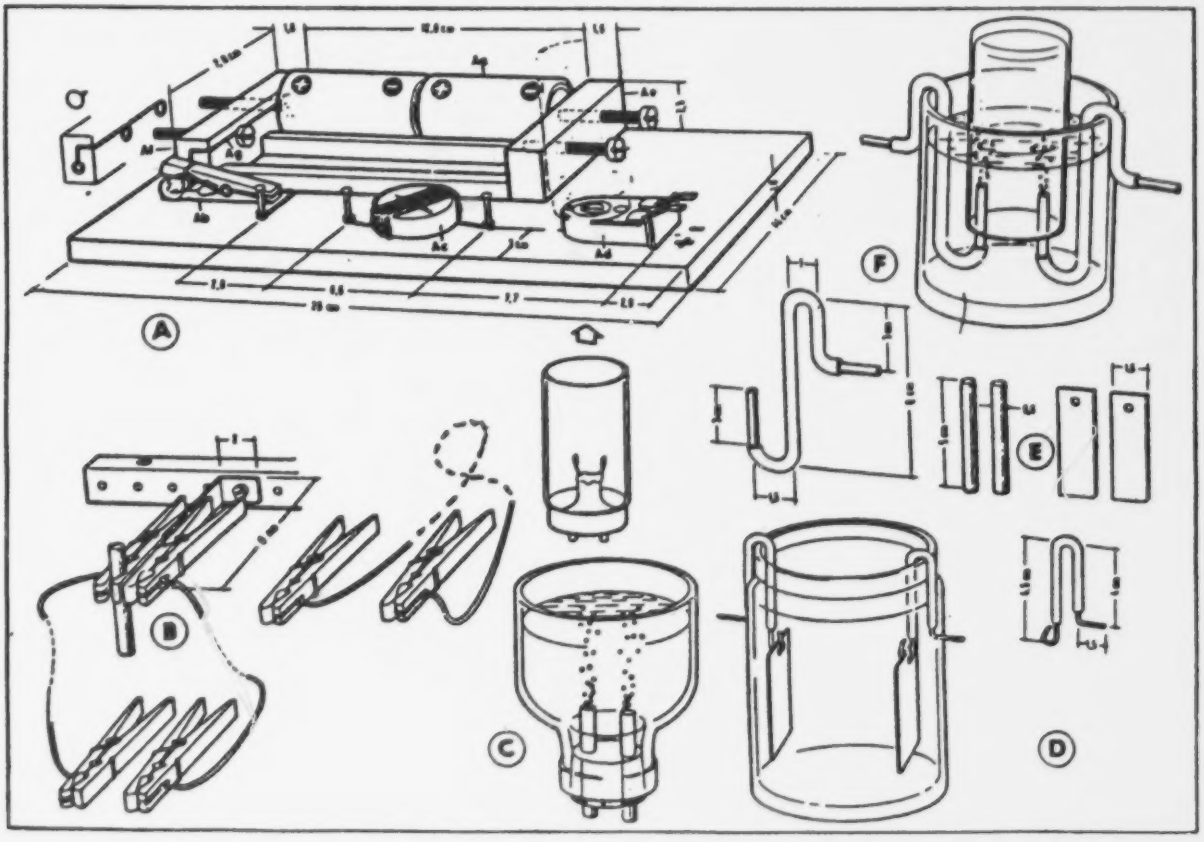
- compact seminars lasting 1 or 2 days which serve to familiarize teachers and administration staff members with the possibilities and limitations of making and using self-made teaching aids.

In the light of experience so far, the most efficient method, from both the economic and subject-related points of view, is the production of standardized basic teaching aid kits as part of pre service teacher training. In Bolivia, for example, students have for some years been making a kit of this type themselves, and taking it with them as their personal property to their first school post, which is normally in a remote area. Similar action is intended in Nicaragua. In both countries, the students also receive training with imported teaching aids. This dual strategy prepares them for emergency situations where previously they would have been restricted to theoretical instruction with blackboard and chalk as well as for situations

where teaching aids already exist. As young teachers, they are at the same time innovators for comprehensible experimentally based education in the schools. Experience so far has shown that young students who take pleasure in experimenting can more easily be motivated or even committed to making a material contribution of their own towards their future professional success and, during their studies, experiments with a practical basis can be carried out and reflected upon over a relatively long period.

On the following two pages examples of home-produced low- or no-cost teaching aids are shown.





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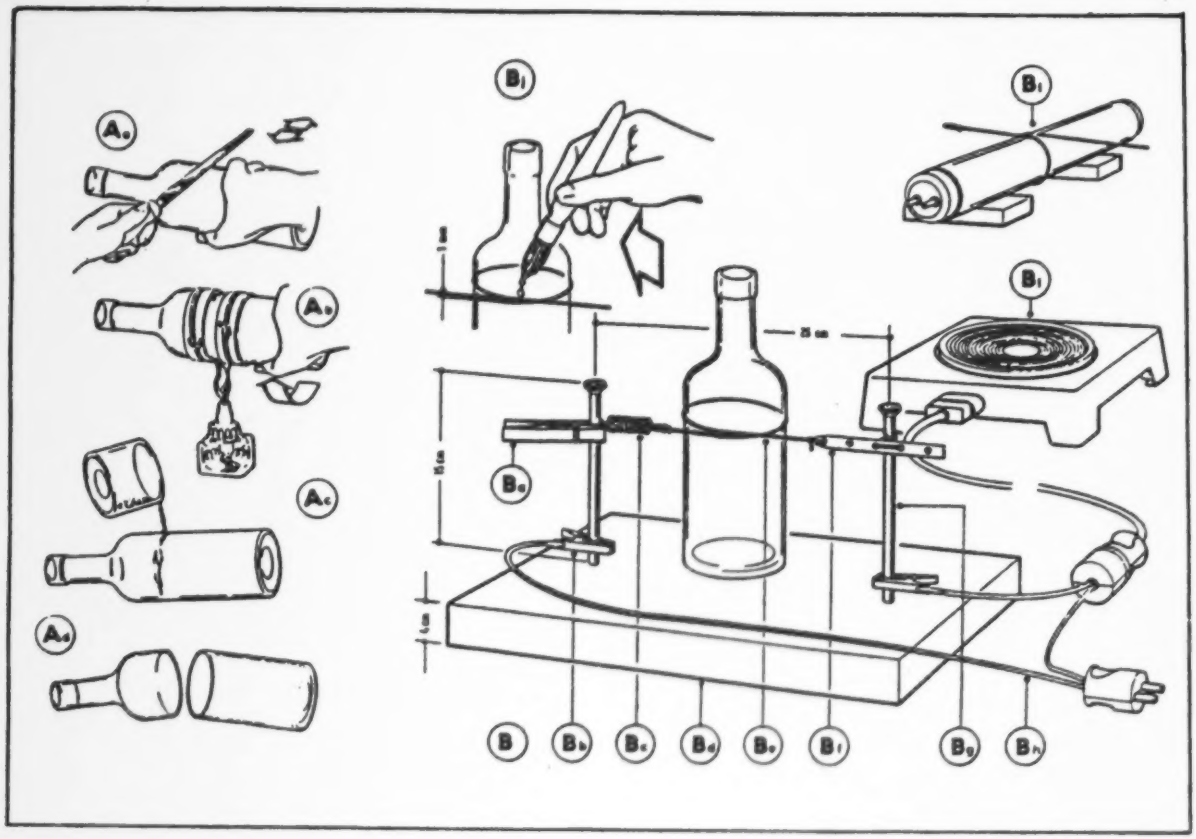

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ZERO COST ELECTRODES FOR ELECTROCHEMICAL MEASUREMENTS

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Introduction

When the equipment for measurement of pH and conductance can be made low cost, it becomes necessary to find cheap substitutes for expensive accessories like a platinum electrode, some ion-selective electrodes, a glass electrode and a conductance cell. It has been found that replacements exist for these items which are satisfactory in performance yet negligible in cost. These nearly zero cost accessories can, of course, also be used with the conventional equipment, especially in the student laboratories.

Method of preparation

We discuss in this section the method of preparation giving only the salient points. Additional details may be obtained from the references at the end which in turn contain references to the earlier literature.

Electrodes for potentiometric measurement

It is found that a carbon rod extracted from a used dry cell can be used for monitoring H^+ ions via a quinhydrone electrode. It is necessary, however, to clean the electrode to obtain reliable performance. The procedure followed involves sandpapering the extracted rod and then immerse it for a day in a dilute solution of chromic acid, i.e. 0.2 M $K_2Cr_2O_7$ in 1 M H_2SO_4. The rod should be thoroughly washed

with destilled water. To check its response, place it in a buffer solution saturated with quinhydrone. Connect this half-cell to a calomel half-cell and measure the EMF of the resulting cell. If the observed EMF shows no drift for about one hour, the carbon electrode is ready for use. A drifting EMF indicates that the carbon should be recleaned as described above.

A quinhydrone electrode has two well-known limitations namely that it is not reliable above pH 9.0 and that the addition of quinhydrone contaminates the test solution. The use of a glass electrode is one alternative, but unfortunately the commercial variety is too expensive for use in student laboratoires. A simple solution to this problem is to blow thin bulbs using a soda lime (i.e. soft glass) test tube. Fill the bulb with 0.1 M HCl and take a connection with either Ag/AgCl wire or quinhydrone with carbon rod in it. This is responsive to H^+ ions. The response is better the thinner the bulb. There is some indication that the nature of the internal solution also affects the response, but this matter needs to be studied further, e.g. in NaCl internal solution with Ag/AgCl electrode in the ordinary without blown test tube responds to H^+ ions.

In order to carry out some of the potentiometric measurements one requires the electrodes like Ag, Zn, Cu etc. These electrodes can also be designed with the help of carbon rod extracted from used dry battery. Take the carbon rod and electroplate the material one requires by just passing the current between this rod and another cathode. The electrolyte should be the salt of electroplated matieral, e.g. for Zn one should take $ZnSO_4$ solution.

There are some experiments in which the amount of individual species is required in a mixture of the solutions. This can easily be done if one uses the ion-selective electrodes, e.g. glass electrode, described earlier, is responsive to H^+ ion. The method of the constructions of solid-state membrane ISEs, like Cu^{2+}, Ag^+, Pb^{2+}, Cd^{2+}, Cl^-, Br^-, I^-, S^{2-} is similar.

We will mention here the construction of Cu^{2+}, the others can be made identically: Mix 100 cm^3 of 1 M $AgNO_3$ with 100 cm^3 of 1 M $Cu(NO_3)_2$ and pass H_2S gas through the solution until co-precipitation is complete. This co-ppt. is washed with hot distilled H_2O, filtered and dried below 100°C. The dry co-ppt. is ground to a fine powder and a pallet is made by using a press and a die. The pallet being stable in air and water can be kept indefinitely. It is mounted on a glass tube with the help of araldite. To obtain an electrical connection, dip an Ag/AgCl electrode in 0.1 M $CuCl_2$.

Electrodes for conductometric measurements

Take two cleaned carbon rods (cut to a suitable length) and insert them through a two holed rubber cork which in turn is inserted in glass tube of appropriate diameter and length. The electrode rubber interface and the glass rubber interface is freely coated with araldite to provide firm finaling. The exposed rubber surface inside the glass tube is also coated with araldite to protect it from attack by common chemical reagents. It has the advantage that the cell can be used as a titration vessel. It has also limitations that is, i) one cannot carry out the non-aqueous titration since araldite dissolves in non-aqueous medium like benzene, and ii) one cannot carry out the precipitation titration since stirring is a problem.

All the limitations of the above mentioned design are overcome by inserting the carbon rods (cut to suitable length) sideways. Some skill in glass blowing is required as the holes have to allow for tight fitting of the electrodes.

Results and discussion

Most of the ordinary experiments, like acid-base titrations, oxidation-reduction titrations, etc. using carbon rods with quinhydrone electrode have been carried out in the international workshop in May 81, at IIT Madras, India and found that these carbon rods respond well. The E^0-value and

the slope of E (V) Vs pH plot is found to be 430 mv Vs. SCE and 54.5 mV pH^{-1} unit respectively for carbon rod. Similar results were observed for pt-electrode (Fig. 1).

A blown or soda-lime test tube with 0.1 N HCl as the internal solution and Ag/AgCl as electrode responds well upto pH-values 7.0 and this can be extended upto pH 11.0, if we make a calibration curve. Similar results were observed for 0.1 N HCl with quinhydrone and carbon electrode (Table 1). One interesting observation has also been made, i.e. if one takes ordinary test tube (without blown) and take 1 N NaCl with Ag/AgCl electrode, this responds to H^+ ions. At least one can carry out the acid-base titration (shown in Fig. 2).

The results for different ion-selective electrodes have been given in Table 2. These ISEs respond well upto certain concentrations of the individual species, mentioned in the Table 2.

The common and some of the complicated experiments have been tried in the International Workshop in Madras, and it has been found that the conductance cells described earlier respond well.

The ion-selective electrodes herein belong to the so-called glass and solid-state membrane type. There are several other types like liquid-liquid membrane, the hetrogeneous membrane, the enzyme and the gas probe electrodes. Attempts to construct these electrodes are under investigation. The theory behind the glass-electrode with soda lime test tube having 1 N NaCl and Ag/AgCl electrode is not very clear. The efforts are being made to understand its theory.

I express my grateful appreciation to Dr. K.V. Sane of the Department of Chemistry, University of Delhi for encouraging me to carry out the project and to Mr. Parmod Uppadhuay for helping me to provide some of the very useful datas.

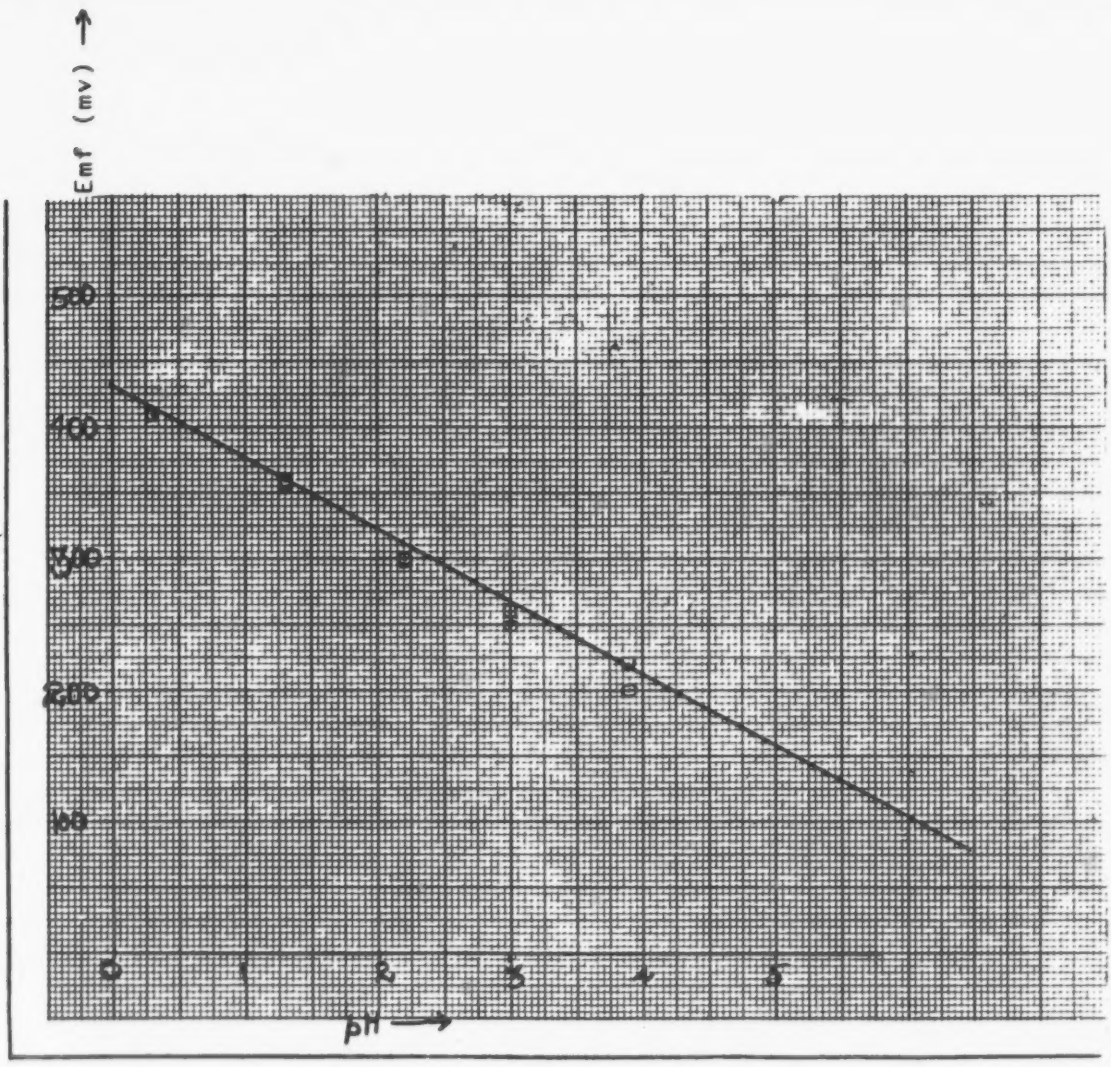

Fig. 1. Comparison of Pt- and carbon-electrode for verification of Nernst equation.

E^0_{quin} = 430 mV Vs SCE in both cases

slope = 54.5 mV pH^{-1} in both cases

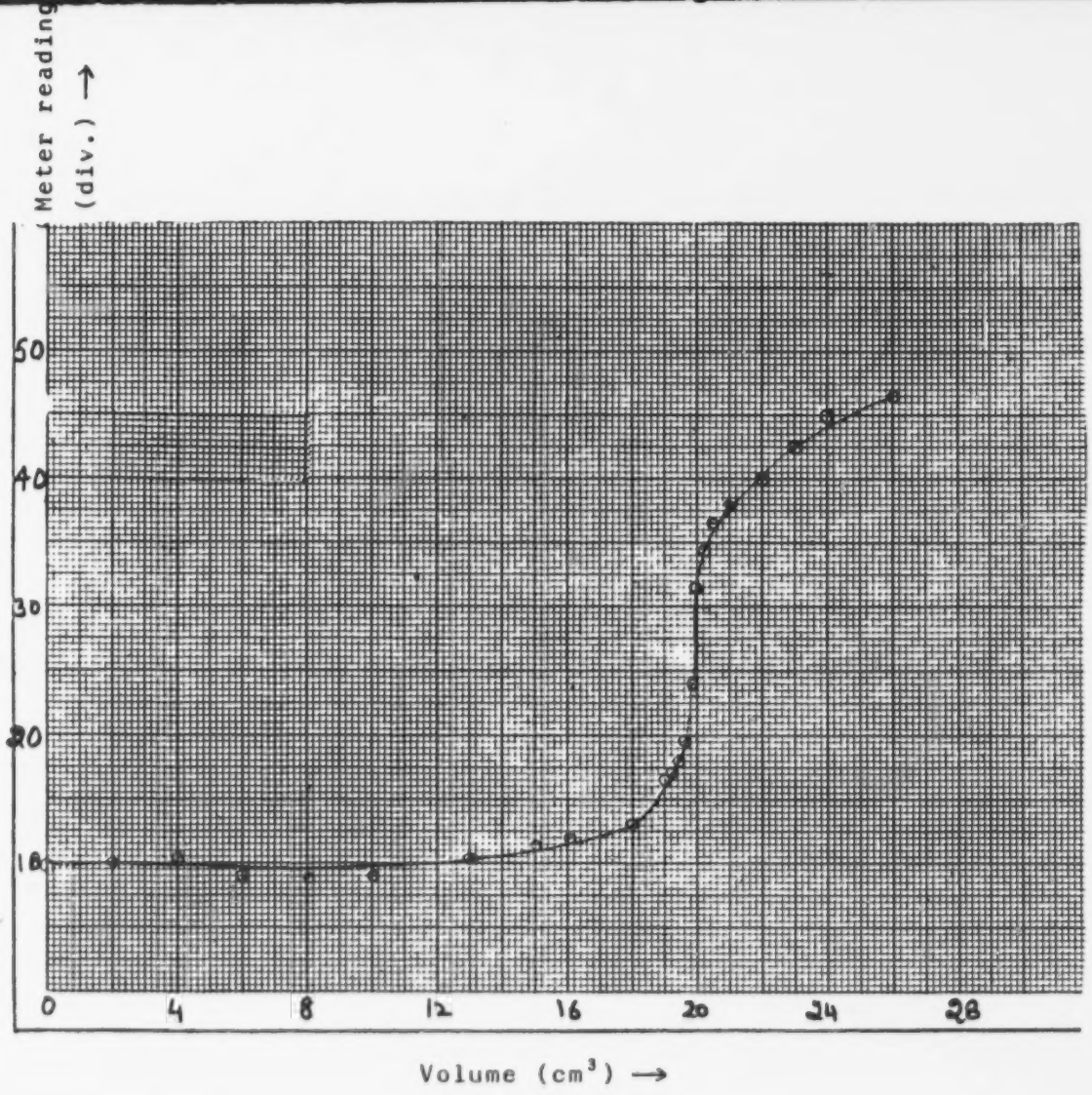

Fig. 2. pH-metric titration of HCl Vs NaOH using ordinary glass test tube with 1 M NaCl as the internal solution and Ag/AgCl as the internal electrode; ref. electrode: SCE.

Table 1: Qualitative Response of blown-glass Electrode.

pH value for solu.	Comm.glass electrode	(A)	(B)	(C)
I	4.85	9.10	8.90	7.75
II	5.90	10.75	10.30	9.35
III	8.40	12.70	12.25	11.55
$pH_{II}-pH_I$	1.15	1.65	1.40	1.60
$pH_{III}-pH_I$	3.65	3.60	3.35	3.80
$pH_{III}-pH_{II}$	2.50	1.95	1.95	2.20

Quantitative response of blown glass electrode using different internal solutions and internal electrodes:

0.1 N HCl internal solution

Ag/AgCl → " electrode

Calibration was done using three standard buffer solutions of pHs 4.0, 7.0 and 9.2 using commercial glass-electrode. pH-values measured on the commercial Elico pH-meter while the absolute emf measurements were done on low cost mv/pH-meter model EdG 05 pH.

cont.

pH-values measured on ELICO pH-meter using		Emf/mV Vs. SCE measured on low cost mV/pH-meter, EdG 05 pH, using	
Comm.glass electrode	Home-made glass electrode	Comm.glass electrode	Home-made glass electrode
2.00	7.10	264	12
2.25	7.15	252	-6
2.40	7.35	252	-18
2.60	7.50	240	-36
2.85	7.70	228	-48
2.95	7.80	222	-60
3.10	7.90	210	-60
3.30	8.05	210	-72
3.45	8.20	192	-84
4.15	8.90	162	-108
6.15	10.70	72	-204
10.40	14.00	-96	-380
11.15	-445 mv	-120	-400
11.45	-455 "	-122	-380

It is observed from these data that pH-values using home-made glass electrode cannot be measured beyond pH 7.00 with commercial pH-meter.

One can now change either the internal solution or the internal electrode which follows:

0.1 N HCl with quinhydrone - Internal solu.
carbon-rod - " electrode

cont.

Similar procedure was adopted as in the previous experiment, but in this, calibration with three buffer solutions was also made on home-made glass electrode, and the same home-made glass electrode was used.

pH-values measured on ELICO pH-meter, using		Emf/mv measured on low cost mV/pH-meter EdG 05 pH, using	
Comm.glass electrode	Home-made glass electrode	Comm.glass electrode	Home-made glass electrode
2.10	2.30	240	168
2.25	2.50	236	150
2.75	2.90	206	138
3.20	3.30	180	120
4.15	4.25	132	84
4.60	4.65	102	66
4.95	4.95	84	48
5.35	5.25	66	36
6.35	6.15	12	0
7.15	7.00	-48	-42
8.35	8.05	-96	-90
9.15	8.75	-144	-120
10.15	9.55	-204	-156
10.75	9.80	-240	-174

Table 2: Response of different Ion-Selective Electrodes.

Temperature = 303 K

Electrode	Ions-sensed	Conc.Range mol dm^{-3}	Slope of Emf Vs. pI mv/pI
Ag_2S	Ag^+	10^{-1}-10^{-6}	62
	S^{2-}	10^{-1}-10^{-5}	-28
Ag_2S-CuS	Cu^{2+}	10^{-1}-10^{-5}	30
Ag_2S-PbS	Pb^{2+}	10^{-1}-10^{-5}	25
Ag_2S-CdS	Cd^{2+}	10^{-1}-10^{-4}	27

Literature:

1) Locally Produced and Low Cost Equipment and Experiments for Chemistry Teaching, UNESCO/IUPAC.

2) P.E. Childs, "Ion Selective Electrodes", School Science Review, Part I, 205 (58), 677 (1977); Part II, 206 (59), 89 (1977); Part III, 206 (59), 503 (1977).

3) C.K. Seth, "Preparation of ion-selective electrode", Ind. J. Chem. Educ. 9 (2) 1982.

A DESIGN FOR A DIRECT READING CONDUCTOMETER

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Introduction

Wheatstone bridge with AC source has dominated the measurement of conductivity of electrolytes ever since the pioneering researches of Kohlrausch. The method being a null technique is capable of great accuracy limited only by the effective length of the bridge wire and by the sensitivity of detectors. The same advantages however become a liability to an undergraduate student as the process of balancing the bridge for amplitude and phase is time-consuming. In addition, the bridge instruments are expensive (approximately US $200 upwards) to impose considerable strain on the limited college budgets in India. Indeed, the only option available to a majority of institutions is to eliminate conductometric measurements at the undergraduate level. It is thus of interest to design a direct reading conductometer using AC in the few kHz range which is as cheap as possible. A relative accuracy of 1% can be considered satisfactory at the undergraduate stage since the subsequent calculations usually involve graphical methods and manual interpolations and extrapolations.

A disadvantage of a direct reading instrument is that the final read-out would depend on the amplitude of the AC and a 1% stability of the amplitude for sinusoidal oscillations requires a rather sophisticated electronics. A square wave oscillator however does not suffer from this disadvantage as the amplitude can be limited by the power supply which can be stabilised to 1% quite cheaply. Since measurement of conductance is frequency independent, a shift to square wave from sinusoidal is of no consequence. The apparent frequency dependencies stem from the electrode processes that can be minimized by going up to a few hundred Hz.

Description of the circuit.

A circuit of an opamp based square wave generator is shown in Figure 1

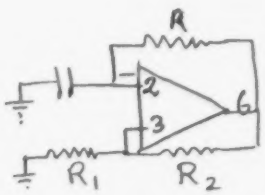

Fig. 1.

The operation of the circuit is well known but it is described here for completeness sake. The opamp is given both a positive and a negative feedback. The former is provided by R_1 and R_2 while the latter is through R and C. The condenser to ground acts like a short at high frequencies. This disables negative feedback for short time scales leaving only positive feedback to remain active. The circuit is therefore unstable and tends to saturate every time it is in the active region. Thus output V_6 is either V_+ or $-V_-$. In the non-active region V_6 remains constant with V_2 charging towards V_6. When $V_2 = V_3 = \alpha V_6 \equiv \frac{R_1}{R_1+R_2} V_6$, the active region intervenes causing V_6 to change suddenly from V_+ to $-V_-$

$$e^{-\frac{\tau}{RC}} = \frac{1-\alpha}{1+\alpha} = \frac{R_2}{R_1+2R_2} \; ; \; \tau = RC \log\left(1 + \frac{2R_1}{R_2}\right) \overset{R_1 \ll R_2}{\Rightarrow} \nu = \frac{R_2}{4R_1RC}$$

If we replace one of the resistance by a conductivity cell, the frequency of the oscillation will depend on the conductance of the solution in the cell. We chose this resistance to be R_1 as in this case the applied potentials are rather low (approx. 1 to 7 volt).

A frequency sensitive detector in conjunction with the above oscillator would yield a complete measuring instrument. A simple arrangement is shown in Fig. 2. The condenser is charged alternately to $\pm C_M V_S$. The charge is steered to go through a meter by two diodes resulting in a current proportional to ν . The arrangement is effectively an analogue frequency meter which counts twice in every cycle. For typical parameters used in the circuit, the linearity of detection of frequency has been found to be better than a fraction of 1%.

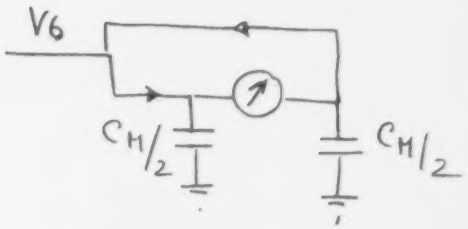

Fig. 2.

The only disadvantage of this detector circuit is the low duty cycle i.e. the fraction of the time that current flows through the diode is very small (only during charging). Hence rather large peak currents are involved. The output V_6 thus has to be buffered via a pair of output transistors. Without this the highest usable frequency drops markedly affecting the readings adversely at high end. With the pair AC 127/8 the output current rises sufficiently so that theupper end is controlled by the slew rate of the opamp.

The buffer transistors also help in increasing the upper limit of conductivity measurement by allowing the use of lower values for R_2. In practice, it has been possible to obtain an instrument which can measure solution resistances from 20 Ω to 50,000 Ω with an accuracy of 1%. The only components of 1% tolerance are the R_2s of the range selector. All other components are of 10% tolerance. Their combined effect is reflected in the calibration curve which is a straight line for the top 80% of the scale. The calibration graph is obtained by replacing the cell by known resistances and it is independent of the range settings.

Results and Conclusion

Satisfactory results have been obtained with this conductometer in over fifty experiments. Detailed comparison of the results with those obtained with domestic and imported commercial models have shown no significant differences. It thus appears that this design is a good compromise between cost and performance. The model seems to be particularly suitable for work at the undergraduate level.

LOCALLY-PRODUCED SCIENCE EQUIPMENT: POTENTIALITIES AND PROBLEMS

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INTRODUCTION

The title of this paper is probably too generalised. It should be made clear that the paper represents an attempt to describe some of the work done in the Caribbean in recent years on the development of locally-produced equipment, which is followed by a consideration of some of the more general issues related to locally-produced equipment. One issue of nomenclature needs to be clarified. The term "locally-produced" is preferred to "low cost" since there are often hidden real costs of "low cost" equipment, particularly at an institution which has been largely financed by government funding, or bilateral or international aid. Thus, even though the costs to the eventual consumers (schools and other institutions) may be low, these are not the only costs to be considered. In addition, we should also consider whether or not locally-produced equipment can be relevant to the needs of all types of institutions, and, if so, what strategies will be needed to develop and utilise such equipment.

Review of Progress in the Caribbean

This is not intended as an exhaustive survey but as an impressionistic outline of some of the developments in the Caribbean in recent years. Clearly, individual teachers and/or institutions have developed their own materials for teaching science in different parts of the Caribbean. One institution which was involved in such developments in the late 1960s and early 1970s was the Science Education Centre, U.W.I., Jamaica, at which Dr. K. Warren worked. One significant event in the 1970s was the workshop organised by the Commonwealth Secretariat in 1976 in the Bahamas. This brought together science educators from not only the Caribbean but also from other parts of the world, with consultants coming from Kenya and India for example. At least one country, Guyana, followed up the initiatives developed at the 1976 Bahamas workshop and organised a*TVC on equipment production in 1977. Work was also done on producing some items of science equipment in the Community High Schools in Guyana. A Low Cost Equipment Workshop is due to begin to function in New Amsterdam (Guyana) at some time, but shortage of funds has meant that the completion of the building has been delayed.

A recent initiative involved the use of the model developed by the Edutronics Group in Delhi, India, at a workshop held in Guyana from August 2 until August 10, 1983.

*Teacher Vacation Course

The Guyana Low Cost Equipment Workshop, August 2 - 10, 1983

The workshop was held at the Chemistry Department, University of Guyana. It lasted for eight working days with the principal resource person being Dr. P. Srivastava, of the Physics Department, University of Delhi. He was assisted by Mr. C. Persaud, Chief Technologist of the Chemistry Department, U.G. The basic administration necessary for the workshop was the responsibility of the Science Adviser to the Ministry of Education, Social Development and Culture. The funding for the workshop was provided by UNESCO, COSTED, IUPAC CTC, Commonwealth Foundation, Department of Science and Technology, India, and I.A.S.T. (Guyana). There were 19 participants in all, 15 from Guyana and one each from Jamaica, Barbados, Trinidad and St. Kitts.

The participants worked in pairs, and each pair assembled and used one pH meter and one conductometer, using components brought by Dr. Srivastava.

Many of the participants were not familiar with elementary electronics and techniques of soldering but the confidence engendered by successful completion of the two specified items should stand them in good stead in the future. This confidence was a direct result of the teaching technique adopted by Dr. Srivastava.

Proposed Future Developments

It should be stressed that the production of the specified items of equipment was not seen as an end in itself, but as one means to achieve particular ends, of which perhaps the most important is the development of skills and confidence in the utilisation of these skills. Thus, the participants will be in a position to look at other items of equipment with a view to developing their own versions.

In the near-to medium-term future, it is hoped that there will be a three-stage process of development within the Caribbean:

(i) Creation within each country represented of one or more "core teams". These teams would have sufficient skill and expertise to carry out further workshops in their countries. This in turn implies that there will be "mini-workshops" in each territory at which the workshop skills of the team members will be developed and refined. Hopefully, these teams will be developed in the next year or so.

(ii) The core teams will carry out national workshops, replicating the work carried out at the Guyana workshop. This should help to meet the needs of the countries involved for the specific items of equipment

as well as begin to sensitise teachers, lecturers and technicians to the needs for locally produced equipment.

(iii) There should be a regional workshop in 1985 at which developments to that time would be reviewed, and future needs identified. Each country/territory should send a minimum of two persons to the workshop, each of whom being prepared to act as resource persons for future national workshops.

If this strategy is to be developed successfully, there are a number of issues to be considered. These include:

(a) Sources of funding for the various workshops (e.g UNESCO, Commonwealth Foundation etc.)

(b) Identification of appropriate institutions and persons. (Particularly important for countries other than Guyana, since each country was represented by one person only at the Guyana workshop.)

(c) Definition of national and regional needs in terms of chemistry and/or science equipment.

(d) Attitudes of teachers and decision makers to development of locally produced equipment.

The strategy outlined above may work in the context of the Caribbean. Nevertheless, it represents only one tentative step in a possibly desirable direction. There is a need to consider some of the more general issues relating to the production of locally produced equipment, since it is likely that many countries are facing similar problems. These relate to the need for science courses with a strong practical component, and the high costs of much imported science equipment. It is not possible to consider all of the issues within the confines of a brief paper but some are outlined below.

Some General Issues

1. What Strategies are available?

There are a number of strategies which have been utilised in different parts of the world to try to ensure effective local production of science equipment. These include:

(a) Production of kits - e.g. SEPU (Kenya), NCERT (India), IPST (Thailand) etc.

(b) Production of selected individual items - e.g Delhi Edutronics, SEPU, IPST etc.

(c) Improvisation/Replacement at the local level.

(d) Commercial production of specific items.

It is suggested that, in any particular context, each of the possible strategies available should be reviewed in the light of the constraints imposed in that context. There is no uniquely correct solution to a particular problem, at least in terms of general principles. We need to consider experience gained elsewhere and examine the strategies utilised to see whether these are applicable in our own context.

It should be said that the value of any one particular strategy may vary with the level of education for which equipment is required. For example, improvisation/replacement may be a fruitful approach at the primary level, but less so at other levels. But, this depends in turn on the attitudes of decision makers, teachers and students towards locally produced equipment. All too often, the perceived status of imported items is greater than that of locally produced items. There is much work to be done in changing attitudes towards locally produced materials. One important point, at present: these items should have good visual appeal, since otherwise many will feel that they are being presented with "second best" material.

2. Which relationships should be considered?

Locally-produced science equipment does not occur in a vacuum. The need for such equipment may be defined clearly within a particular context, which will not simply include the education system. But, for those who might wish to become involved in local production of science equipment, there are a number of inter-related factors to be considered. These include:

(a) The local science curriculum (at the appropriate level), and the examinations related to such curricula.

(b) The style and content of teacher training. One advantage, for example, of the SEPU model, is its proximity to Kenya Science Teachers College.

(c) The style and content of technician training. Both technicians and teachers will need to be aware of the possible approaches to locally produced equipment, and the need for fruitful relationships, e.g with school I.A. departments.

(d) Attitudes of decision-makers in the Ministry of Education and elsewhere.

(e) Role of Science Teachers' Associations (e.g. Thailand, Hong Kong).

3. What are some of the constraints?

Even if there is a well-thought out programme for the development of locally produced material and some (or all) of the necessary relationships have been considered, there will be constraints to be faced. These include:

(a) Attitudes of the local bureaucracy, both within and without education. This will often relate to:

(b) Attitudes to innovation. Many people are frightened of innovation, particularly if it is thought to threaten their authority/power in some way.

(c) The perceived status of science. Science does not necessarily have a high status, e.g. in primary schools in some countries. And, locally-produced equipment might contribute to a lowering of status, because of (a) and (b) for example.

(d) Time scale. It is often overlooked that it takes a considerable time for educational innovation to take root within a system. Much preparation has to be done to try to ensure that new approaches are accepted over the broad range of a system.

(e) Political and economic infrastructure. This relates in part to (b), since a positive attitude to innovation at the political level may eventually have an impact on local decision makers.

4. Where to now?

The heading of this section is not in the form of elegant language, but it does perhaps help to focus our thoughts. Clearly a good deal of work has been and is being done to try to develop and use locally-produced science equipment. It should be said that there are no universal prescriptions for success, but we can perhaps learn a great deal from successful innovations. In any attempt to consider the near - to medium - term future, we should perhaps consider some or all of the following:

(a) Whatever strategy is adopted, it is important to have the strategy firmly rooted in local conditions, even if external funding and support also has value, particularly in the eyes of local decision makers.

(b) There is need to consider how to introduce principles of local production of equipment into both teacher and technician training.

(c) There is need to look at the present and future role of practical work in school science courses, since this will in turn have a direct influence on the type of equipment required.

(d) It may be possible to extend the strategies so far developed to other levels and subjects.

This very brief overview can only be regarded as an outline of some of the problems. But, the potentialities for development of locally produced equipment are considerable, provided we ensure that good schemes are well supported both within and without the country concerned.

SPECTROSCOPY ON PARTIALLY ORIENTED SAMPLES

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INTRODUCTION

In optical spectroscopy the absorbance for a given electric dipole transition o→f in a molecule can usually be assumed to be proportional to the square of a quantum mechanical integral, the transition moment

$$\underline{M}_{of} = \langle o|\hat{\underline{M}}|f\rangle$$

where $\hat{\underline{M}}$ is the electric dipole operator. Clearly $\underline{M}_{of}$ is a vector and defines a specific direction in the molecule. This property is usually neglected, but the direction can in many cases be determined experimentally by a simple and low-cost technique.

This is possible since the light absorption by a sample of molecules which are not randomly oriented in general depends on the orientation of the electric vectors of the light relative to the sample. If for instance the light is linearly polarized with the electric vector along a direction $\underline{U}$ and the sample consists of perfectly aligned molecules with transition moments $\underline{M}_{of}$ along a specific direction $\underline{V}$, the measured absorbance becomes proportional to $\cos^2(\underline{U}, \underline{V})$. Thus the absorbance is largest when $\underline{U}$ and $\underline{V}$ are parallel and zero when they are perpendicular. For a general non-random orientation the absorbance due to a transition from a ground state o into an excited state f is proportional to the average over all molecules in the samle of the cosine square to the angle between

the electric vector of the light and the transition moment of the f'th transition, $\langle \cos^2(\underline{U}, \underline{M}_{of}) \rangle_{av}$. By choosing two different directions $\underline{U}$ for the electric vector two different spectra may be produced from which information on both transition moment directions $\underline{M}_{of}$ and on the molecular alignment may be obtained as shown below (1 - 3).

EXPERIMENTAL

The main experimental problem is the production of molecular alignment in the sample. This may be done conveniently by means of anisotropic solvents such as stretched polymer sheets. Many linear polymers can be oriented by stretching (or extrusion). Often the orientation becomes uniaxial: all directions perpendicular to the stretching direction are equivalent. This is even the case when relatively thin films are stretched, and in the following it will be assumed that the orientation is of this type. The molecules of interest, the substrate, may be introduced into the polymer in a number of ways, e.g.:

1. Swelling the polymer with a solution containing the substrate.
2. Casting a film of the polymer from a solution to which the substrate has been added.
3. Letting the vapor of the substrate diffuse into the polymer.
4. Dissolving the substrate in a molten polymer.

In all cases the stretching of the polymer may be performed after the doping, but for methods 1 and 3 it can also be done before. When using methods 1 and 2 it is important that all solvent evaporate before the spectra are recorded, and in method 1 all crystalline residue which may have appeared on the surface of the film should be removed with a solvent which does not swell the film.

The determination of the amount of solute in the sample may be a problem if methods 1 and 3 are used. In many cases it is done by running a spectrum in a liquid solvent of similar composition as the polymer and assuming that the extinction coefficients are the same as in the polymer.

Additives or impurities are often found in commercial polymer sheets, and they should be removed by extraction with a solvent which swells the polymer.

The polymers enjoying the highest popularity are poly(vinylalcohol) and polyethylene. They are both transparent in the uv-visible region down to around 200 nm. Poly(vinylalcohol) is less convenient in the ir region, whereas polyethylene is transparent except for some narrow regions around 750, 1450, and 2900 cm^{-1}.

The stretching may be done by hand, but simple mechanical devices can easily be constructed (4, 5). In the case of poly(vinylalcohol) the stretching should be done at an elevated temperature, e.g. using hot air from a hair dryer. Polyethylene sheets are usually stretched at room temperature to around 4 times their original length. After they are released they retract a little and then keep their elongated shape. Poly(vinylalcohol) sheets can be stretched more and contrary to polyethylene the solute alignment improves by further stretching.

For non-polar solutes polyethylene sheets are very convenient, and usually method 1 is used for the introduction of the solute into the polymers. Chloroform is a suitable solvent in this case. The sheet may be dipped into the solution, or a drop of the solution may be placed on the sheet, depending on the concentration needed.

For polar solutes poly(vinylalcohol) is most convenient, and method 2 is often used. Commercial poly(vinylalcohol) powder and the substrate is dissolved in water and heated

to produce a thick homogeneous solution containing 10 % of the polymer. Generally, bubbles and dust should be avoided. This solution is then cast on a glass plate, and the water is allowed to evaporate, which may take days. The film can then easily be peeled off. A more detailed description of the process is given in ref. 4.

For the recording of spectra the use of polarizers is recommended although the effect of orientation can also be observed with unpolarized light. In the visible region very inexpensive sheet polarizers of the Polaroid sunglass type can be used. These are themselves basicly chains of iodine atoms aligned in a stretched (or extruded) poly(vinylalcohol) sheet. Sheet polarizers are also available for the uv and ir regions.

When a stretched sheet is used, two spectra are recorded, both with the direction of light propagation, X, perpendicular to the plane of the sheet. In the first spectrum the electric vector of light is along the stretching direction Z, in the second the electric vector is along Y, perpendicular to the sample axis.

Since it is the solute absorbance which is of interest, the contributions from polarizer and sheet must be subtracted. This may be done in a double beam instrument by placing a polarizer and an empty sheet in the reference beam, oriented like those in the sample beam. Another possibility is to record the absorbances of the polarizer and empty sheet separately and subtract these from the corresponding absorbances of the original samples.

It should be noted that in some spectrophotometers the light beam is partially linearly polarized. Often it will be an advantage to record the two spectra with the electric vector of the light at angles $+45^0$ and -45^0 to the vertical.

EVALUATION OF THE SPECTRA

In the following a simple evaluation method for dichroic spectra which is often called the TEM method will be described (1 - 6). The observed absorbances with the electric vector of the linearly polarized light along the unique sample axis (stretching direction) Z and along Y are called $E_Z(\lambda)$ and $E_Y(\lambda)$, respectively. If a spectrum could be measured with the electric vector along X, the absorbance $E_X(\lambda)$ would be equal to $E_Y(\lambda)$ because of the uniaxial property of the sample. The sum

$$E_Z(\lambda) + E_Y(\lambda) + E_X(\lambda) = E_Z(\lambda) + 2\,E_Y(\lambda)$$

is equal to three times the absorbance $A(\lambda)$ which would be measured on a randomly oriented sample of the same concentration:

$$E_Z(\lambda) + 2\,E_Y(\lambda) = 3\,A(\lambda)$$

$A(\lambda)$ may be written as a sum of contributions $A_f(\lambda)$ from transitions o→f:

$$A(\lambda) = \sum_f A_f(\lambda)$$

Since the contribution to $E_Z(\lambda)$ from transition f is proportional to $\langle\cos^2(Z,\underline{M}_{of})\rangle_{av}$ which will be written K_f:

$$K_f = \langle\cos^2(Z,\underline{M}_{of})\rangle_{av}$$

and since K_f for all transitions in a random sample is equal to 1/3, we have:

$$E_Z(\lambda) = \sum_f K_j\,A_f\,(\lambda)$$

Now,

$$E_Z(\lambda) + 2\,E_Y(\lambda) = \sum_f A_f(\lambda)$$

and we have

$$E_Y(\lambda) = \frac{1}{2} \sum_f (1-K_f)\, A_f(\lambda)$$

The contribution from the f'th transition, $A_f(\lambda)$, disappears from the linear combination

$$E_Z(\lambda) - E_Y(\lambda) \cdot 2\, K_f/(1-K_f)$$

This means that if the transitions are non-overlapping (which is usually the case in ir), we have

$$2\, K_f/(1-K_f) = E_Z(\lambda_f)/E_Y(\lambda_f) = D(\lambda_f)$$

where λ_f is the wavelength of the peak due to the f'th transition and $D(\lambda)$ is called the dichroic ratio. Now K_f can be experimentally determined:

$$K_f = D(\lambda_f)/[2 + D(\lambda_f)]$$

K_f can also be determined in the case of overlapping transitions (common for visible-uv spectroscopy). A set of linear combinations

$$E_Z(\lambda) - d \cdot E_Y(\lambda)$$

are constructed, and the one in which the spectral features (peak, shoulder, etc.) due to transition f disappears is determined. The corresponding value of d is called d_f. We have

$$2\, K_f/(1-K_f) = d_f$$

and

$$K_f = d_f/(2+d_f)$$

(K_Y, K_Z) values determined this way for a large number of aromatic hydrocarbons aligned in polyethylene are shown in Figure 1. Obviously the alignment depends on molecular

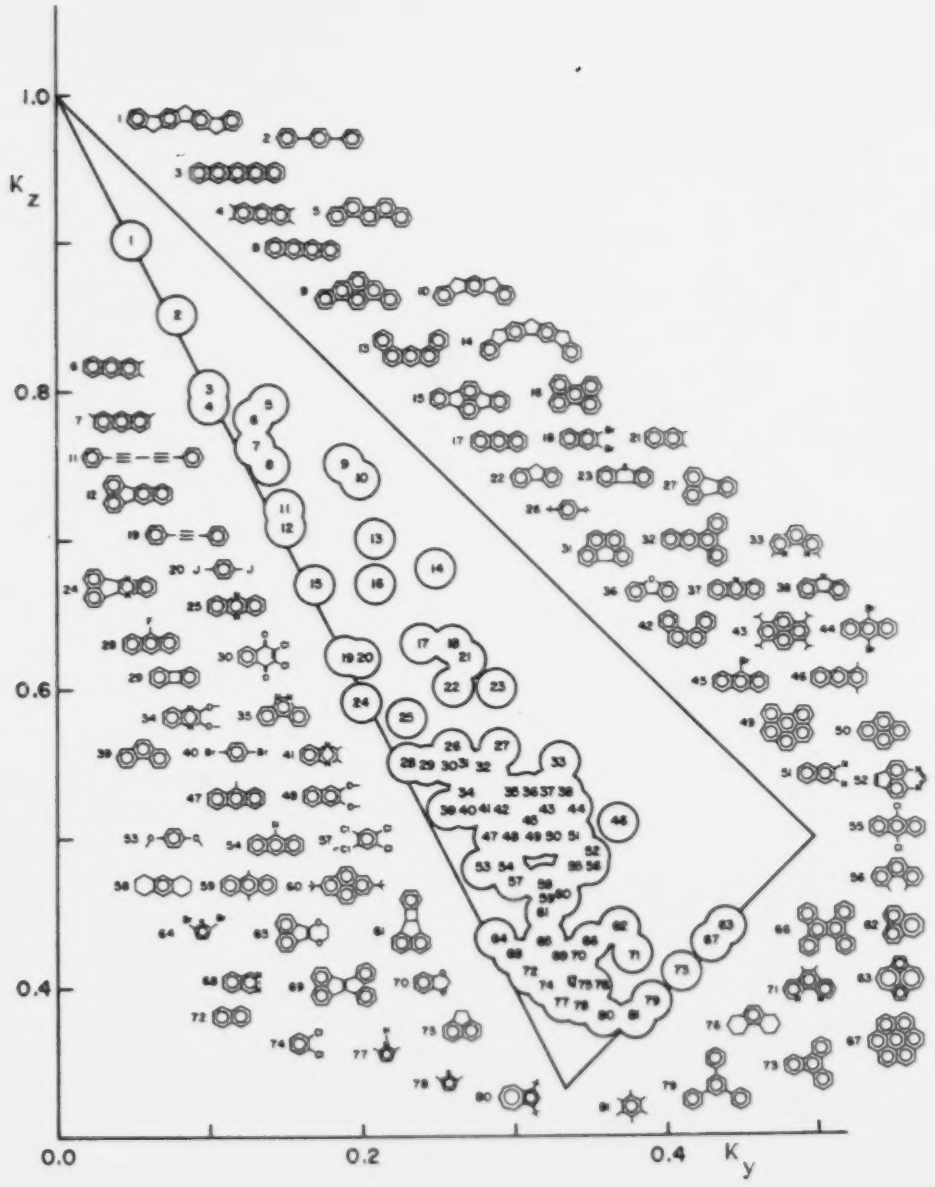

Fig. 1. Values of (K_y, K_z) for aromatic hydrocarbons in stretched polyethylene at room temperature (1). The molecular orientation axis z is horizontal and y is vertical for all molecules. The lower corner of the triangle corresponds to random orientation, the top corner to perfect alignment.

shape, and the molecular long axis becomes z, the one corresponding to the highest K-value. The triangle in the figure shows the theoretical limits for (K_y, K_z) values: left side: $K_x = K_y = (1-K_z)/2$ (rod-shaped molecules), bottom: $K_y = K_z = (1-K_x)/2$ (disc-shaped molecules), and right side: $K_y+K_z = 1$, $K_x = 0$ (perfect plane alignment). Thus from the observed molecular alignment information on the molecular shape can be obtained. Note that also small molecules such as chloroform can be aligned in polyethylene.

High symmetric case:

If the molecular symmetry point group is so that the molecular axes x, y, z belong to different irreducible representations (e.g. C_{2v}, D_{2h}) all transition moments must be directed along x, y, or z. Then only three different K_f-values exist: K_x, K_y, and K_z. We label the axes so that $K_x \leq K_y \leq K_z$ and from the definition $K_x+K_y+K_z = 1$. Thus the K's are not independent. In many cases the sum of contributions to the absorbance due to transitions polarized along x, y, or z, e.g.

$$A_z(\lambda) = \sum_{f}^{\text{M of along z}} A_f(\lambda)$$

can be separated. One such case, common in many important molecules is that of $A_x(\lambda) = 0$ in a large spectral region (e.g. when only π-π^* transitions are present). Then $A_y(\lambda)$ and $A_z(\lambda)$ can be determined:

$$A_y(\lambda) = [2 K_z E_Y(\lambda) - (1-K_z)E_Z(\lambda)]/(K_z-K_y)$$

$$A_z(\lambda) = [(1-K_y)E_Z(\lambda) - 2 K_y E_Y(\lambda)]/(K_z-K_y)$$

Figure 2 shows an example of separation of π-π^* absorption into $A_z(\lambda)$ and $A_y(\lambda)$.

The separation of the spectrum into contributions from transitions of different polarization is very useful for spectral assignments and for the detection of hidden transitions

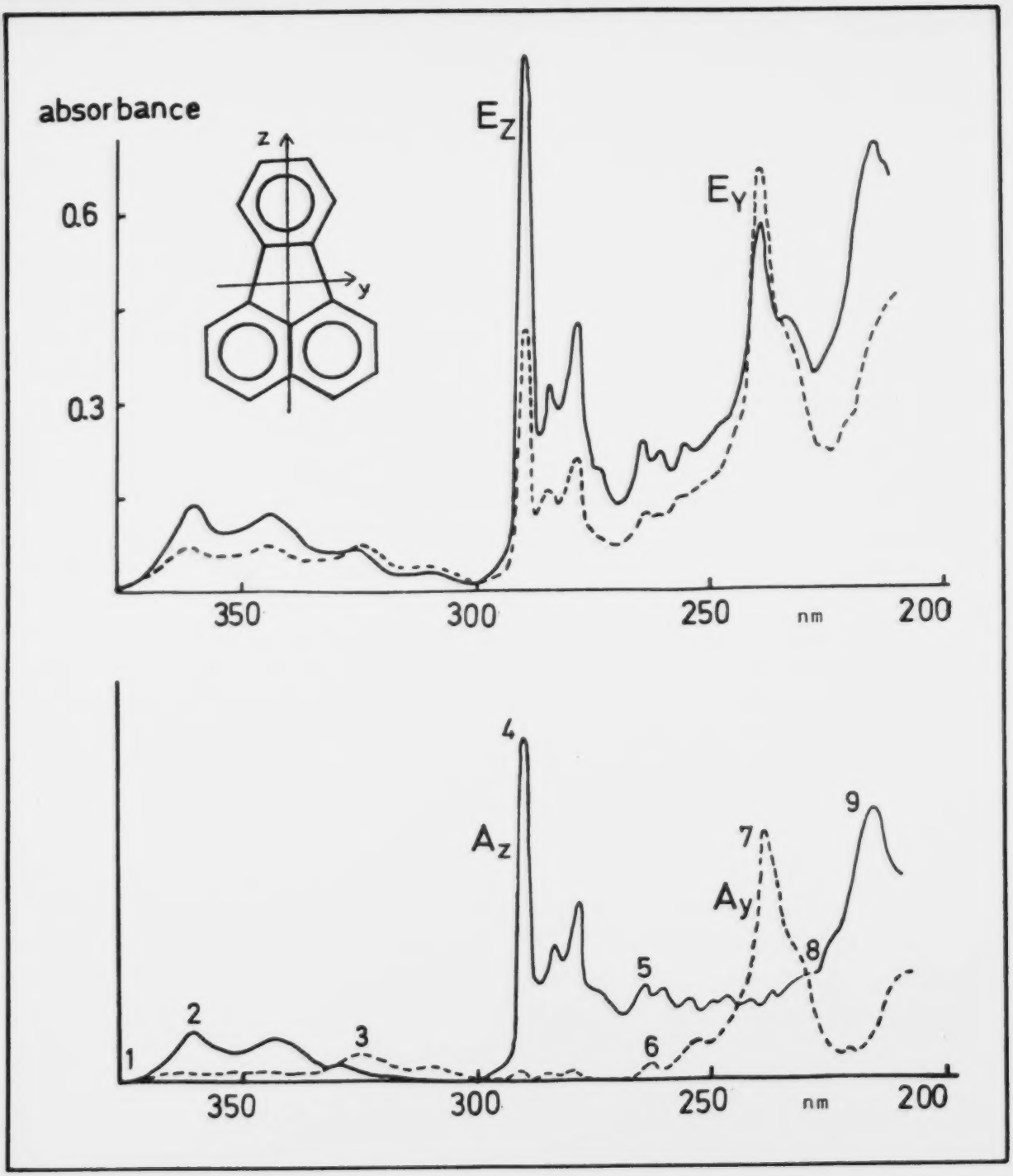

Fig. 2. Top: The spectra $E_z(\lambda)$ and $E_y(\lambda)$ observed for fluoranthene aligned in stretched popyethylene at room temperature (3). Bottom: Absorbance due to z-polarized transitions (A_z, full line) and y-polarized transitions (A_y, dashed line) determined as linear combinations of E_z and E_y as described in the text.

in regions with considerable overlap (3). It is also essential for the teaching of visible-uv spectroscopy on a quantum chemical basis. The separation may be performed also in other cases than that of $A_x(\lambda) = 0$ shown here (1, 3).

Low symmetry case:

In molecules of lower symmetry $\underline{M}_f$ can be directed along any direction in the molecule and the molecular axes are no longer given by symmetry. They will be defined so that z is the direction in the molecule with the highest possible K-value, K_z, and x that with the lowest, K_x. The molecular y-axis is perpendicular to z and x. This choice of axes is equivalent to diagonalization of the K-matrix with elements $K_{fj} = \langle\cos(Z,f)\cos(Z,j)\rangle$; f,j = x,y,z. Also in the low-symmetry case detailed information may be obtained from the spectra (1, 3). If for example $A_x(\lambda) = 0$ in a spectral region, the angle between $\underline{M}_{of}$ and z, $(\underline{M}_{of},z)$ will be given by

$$\tan^2(M_{of},z) = (K_z-K_f)/(K_f-K_y)$$

CONCLUSIONS AND SUGGESTIONS

Most molecules may be aligned in stretched polymer sheets. The method is very inexpensive and has considerable advantages over other methods for molecular alignment (e.g. electric or magnetic fields, crystals, etc.). Aligned molecular samples may be used for linear dichroism spectroscopy in the ir, visible or uv regions. Instrumental requirements are low except in the ir region, where high concentrations otherwise are necessary.

The linear polarizers needed are particularly inexpensive for the visible region, where polarizing sheets of the Pola-

roid sunglass type can be used. The effect of orientation may even be studied with the eye in a classroom using an overhead projector.

The experiments can be used for a demonstration of molecular properties, in particular transition moment directions, or of molecular orientation, which is strongly related to molecular shape.

The molecular orientation is described by the K's, which do not completely define the orientation distribution but which contain exactly the amount of information available from the experiment and that needed for the evaluation of the spectral data.

Low cost experiments can be best performed in the visible region, which may also be the most instructional. A number of dyes are recommended in ref. 4; spectra of elongated dyes can be reasonably well described by the "particle in a box" model. A large number of dyes can be used, also less expensive ones than those mentioned in ref. 4. In some cases the dye may be extracted from natural products, e.g. carotene from carrots.

In the uv region reasonably priced sheet polarizers are also available, and in that region aromatic hydrocarbons are ideal substrates. Spectra and transition moment directions from such measurements may be interpreted in terms of simple Hückel theory or the "particle in a box" model.

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W O R K S H O P

S C H E D U L E

THURSDAY, AUGUST 11.

9,00 a.m. - 8,00 p.m.	Registration and check-in. Chemistry Department.
8,00 - 10,00 p.m.	Reception, Chemistry Department. Speaker: Niels E. Rafn, Secretary-General of the Danish National Commission for UNESCO.

Morning Session:

9,15 - 10,30 a.m.	Opening Session:
	David Waddington, UK, Chairman of the IUPAC Teaching Committee
	Henning Andersen, Denmark, President of the Royal Danish School of Educational Studies
	Hanne Søndergaard, Denmark, Member of UNESCO's Executive Board
	Chairman: S.Z. Haider, Bangladesh
	Krishna V. Sane, India: Low-Cost Equipment for Chemical Education
10,30 - 11,00 a.m.	Coffee Break and private discussions
11,00 - 12,00 a.m.	Hans Schmidt, W. Germany: Alternative Sources of Materials and Equipment for Science Teaching
	Mark D. Ellse, UK: Reducing the Cost of Apparatus
12,00 - 2,00 p.m.	Lunch and private discussions

Afternoon Session:

2,00 - 5,30 p.m.	Chairman: P.E. Childs, Ireland
	Short presentation of Posters on permanent display:
	K.V. Sane, C.K. Seth and P.K. Srivastava, India: Low-Cost Equipment for Chemical Education
	S. Storgaard Jørgensen, Denmark: A Simple and Versatile Injection Valve for Flow Injection Analysis
	Hans Schmidt, W. Germany: Workshops in Developing Countries (not confirmed yet)
	Laboratory Demonstrations:
	Mark D. Ellse, UK: Reducing the Cost of Apparatus
	K.V. Sane, C.K. Seth and P.K. Srivastava, India: Low-Cost Equipment for Chemical Education
	Dough H. Maass, W. Germany: Cut Card Chemistry
	D. Krnel, Yugoslavia: Development of Models for Chemistry Teaching
6,00 - 7,00 p.m.	Supper
7,00 - 9,00 p.m.	Private discussions

SATURDAY, AUGUST 13.

Morning Session:	
9,15 - 10,15 a.m.	Chairman: E. Garbowski, France
	S.Z. Haider, Bangladesh: Cheap Cation-Exchanger from Water Hyacinth
	Robert Kalvoda, Czechoslovakia: Modular System with Operational Amplifiers for Measurements in Chemistry
10,15 - 10,45 a.m.	Coffee Break and private discussions
10,45 - 12,00 a.m.	P.K. Srivastava, India: A Design for a Direct Reading Conductometer
	C.K. Seth, India: Zero Cost Electrodes for Electro-Chemical Measurements
	Bill Robertshawe, Sweden: Achieving a Better Life Quality - The Role of Chemical Educators
12,00 - 2,00 p.m.	Lunch and private discussions
Afternoon Session:	Laboratory Demonstrations:
2,00 - 3,30 p.m.	Chairman: R. Kalvoda, Czechoslovakia:
	Nils S. Moe, Denmark: Reference Electrodes
	J.J. Christiansen, Denmark: A Home-Made pH-meter and a Home-Made Photometer
	G. Cederberg, Denmark: Low-Cost Polarimeter
	Peter Norrild, Denmark: A Low-Cost and Low-Risk Cracking Experiment
3,30 - 4,00 p.m.	Coffee Break and private discussions
4,00 - 5,30 p.m.	Optional
5,30 - 7,00	Supper

SUNDAY, AUGUST 14.

11,3o - 2,30 p.m. Brunch at Hotel Scandinavia, (the Brasserie)

Speaker: Knud Vilby, Chairman of the Danish National Commission for UNESCO

The Hotel is located at Amager Boulevard 70 (K 13 on the workshop city map).

It can be reached by foot in 10 minutes or by bus (no. 13) from the Central Railway St.

The Brunch includes bread, rolls, Danish pastry and cakes, herring, meat, hot dishes, desserts, fruit juice, milk, tea, coffee, etc., etc. (Alcoholic beverages may be purchased).

The brunch is included in the meal plan. Other participants, relatives, etc. may sign up for the brunch at a special, very low price of D.kr. 60.-. This should be done Friday at the latest.

MONDAY, August 15.

Morning Session:

9,15 - 10,15 a.m.	Chairman: P.K. Srivastava, India
	E. Garbowski, France Testing Low Cost Equipment for Chemistry
	P.E. Childs, Ireland: Reducing the Cost of Teaching Chemistry
10,15 - 10,45 a.m.	Coffee Break and private discussions
10,45 - 12,00 a.m.	S.Z. Haider, Bangladesh: A Modified Curie-Cheneveau Magnetic Balance
	J. Ruzicka, Denmark: Flow Injection Analysis is a Routine Tool in Agricultural Laboratory in Brazil
	G. Rämme, Sweden: Simulator for Studying Thermodynamic and Reaction Kinetic Phenomena: A Powerful Teaching Aid.
12,00 - 2,00 p.m.	Lunch and private discussions
Afternoon Session:	Laboratory Demonstrations:
2,00 - 5,30 p.m.	Chairman: J.V. Kingston, UNESCO
	P.E. Childs, Ireland: Reducing the Cost of Teaching Chemistry
	Preben G. Sørensen and Thor A. Bak, Denmark: Two Experiments in Physical Chemistry
	D.H. Maass, W. Germany: Simulations for the Teaching of Elementary Kinetics
	J.J. Christiansen, Denmark: Determination of Gas Volume in Urine Bags by Means of a Measuring Wedge or Parallel Plates as Fixed Measures
6,00 - 7,00 p.m.	Supper
7,00 - 9,00 p.m.	Private discussions

TUESDAY, AUGUST 16.

Morning Session:

9,15 - 10,15 a.m.	Chairman: K.V. Sane, India
	J.V. Kingston, UNESCO: Chemistry for Development
	S.F.A. Kettle, UK: Laboratory Work in Three Universities in Thailand
10,15 - 10,45 a.m.	Coffee Break and private discussions
10,45 - 12,00 a.m.	M. Gardner, USA: Trends, Issues in International Chemical Education
	D.E.Ryan, Canada: Establishment of a Centre for Analytical Research and Development in Sri Lanka
12,00 - 2,00 p.m.	Lunch and private discussions

Afternoon Session: Laboratory Demonstrations:

2,00 - 5,00 p.m.	Chairman: M. Selvaratnam, Sri Lanka
	G. Foxcroft, UK: A Physicist's view of Low-Cost Equipment for Science Education
	Hans Schmidt, W. Germany: Low-Cost Equipment Items and a Complete Chemistry Teaching Kit for Lower Secondary Level.
	Peter Norrild, Denmark: A Low-Cost "Nitric Acid Plant"
	Erik W. Thulstrup, Denmark: Polarized Light and Oriented Molecules
6,00 p.m.	Reception and supper at the Town Hall of Copenhagen

WEDNESDAY, AUGUST 17.

Morning Session:

9,15 - 10,15 a.m.	Chairman: S.F.A. Kettle
	J.L.A. French, Nigeria: A Tidal Simulator for the Study of Small Marine Animals
	M. Gardner, USA: Practical Problems of Laboratory Work in Developing Nations
10,15 - 10,45 a.m.	Coffee Break and private discussions
10,45 - 12,00 a.m.	Closing of the workshop
12,00 - 2,00 p.m.	Lunch and private discussions

Afternoon Session: Laboratory Demonstrations:

2,00 - 3,30 p.m. Chairman: M. Gardner, USA

Most equipment demonstrated during Aug. 12-16 will be on display.

THE PARTICIPANTS' IMPRESSION OF THE WORKSHOP

Very helpful	13	
Helpful	9	
So-so	1	(a physicist)
Not helpful	0	
A waste of time	0	
Total	23	

The evaluation was performed by secret ballots during the last lecture of the workshop, and many participants had already left.

L I S T

O F

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